

**WORKING MEMORY AND READING:  
A DEVELOPMENTAL STUDY**

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## ABSTRACT

### WORKING MEMORY AND READING: A DEVELOPMENTAL STUDY

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Models of reading comprehension using the working memory paradigm have been formulated from studies using adult readers. Although there appear to be differences in working memory skills between beginner and mature readers, and normal and reading disabled children, the exact role of working memory in reading is still unclear. This study examined the role of working memory in the development of reading in children. A study by Baddeley, Logie, Nimmo-Smith, and Brereton (1985) was modified for this purpose to accommodate factors relevant to reading development in children.

One hundred and ninety nine normal Std 1, 3 and 5 readers were selected for the study. The children were tested in their classrooms in groups according to their standard of education. The test materials assessed firstly, various component reading skills, namely, phonological coding and lexical access, and reading comprehension, and secondly, verbal and nonverbal working memory. The working memory tests included traditional measures of working memory span, such as the digit and word span tests (verbal), and a dot counting span (nonverbal). Other working memory tests included

complex reading and listening span tests. The language tests relevant to reading in children included vocabulary and listening comprehension.

The results showed strong developmental trends for all reading and working memory measures. The complex reading and listening span tests failed to predict reading comprehension in this group, and only correlated weakly with reading comprehension in the Std 1 subjects. However, they correlated significantly with lexical decision measures in all subjects. The best predictors of reading comprehension were listening comprehension and vocabulary. Reading comprehension correlated significantly with measures of phonology in the Std 1 subject group, and with measures of lexical access in all the subject groups. None of the traditional tests of working memory correlated with reading comprehension. Instead, they correlated significantly with component reading skill tests.

According to the results, the reading span test correlated significantly with, and predicted, the ability to access lexical entries from print. This suggests the presence of a common component, possibly information processing speed. The working memory measures tapped the phonological loop rather than the central executive. However, this may support the view of other researchers that there is a language and spatial processor in working memory instead of a general central executive. This language processor may be situated in the phonological loop and may be

involved in reading. However, further research is required to test this postulate.

DECLARATION

I declare that this dissertation is my own, unaided work.

It is being submitted for the degree of Master of Arts to the University of the Witwatersrand, Johannesburg.

It has not been submitted for any degree or examination in any other University.

Adan

Marilyn Jean Adan

1<sup>st</sup> day of NOVEMBER, 1991.

In loving memory of my parents

Joan and George Paxton

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## TABLE OF CONTENTS

| Page              |   |      |
|-------------------|---|------|
| ABSTRACT          |   | ii   |
| DECLARATION       |   | v    |
| DEDICATION        |   | vi   |
| ACKNOWLEDGEMENTS  |   | vii  |
| TABLE OF CONTENTS |   | viii |
| LIST OF FIGURES   |   | xiii |
| LIST OF TABLES    |   | xiv  |
| <br>              |   |      |
| CHAPTER           |   |      |
| 1.                | BRIEF OVERVIEW                            | 1    |
| <br>              |   |      |
| 2.                | THEORETICAL BACKGROUND                    | 4    |
| 2.1               | EVOLUTION OF THE WORKING MEMORY CONSTRUCT | 4    |
| 2.1.1             | Hypothetical Precursors                   | 4    |
| 2.1.2             | More Recent Hypotheses: Modal Models      | 5    |
| 2.1.3             | Criticism of Modal Models                 | 6    |
| 2.1.4             | Towards a Model of Working Memory         | 8    |
| 2.2               | A MODEL OF WORKING MEMORY                 | 10   |
| 2.2.1             | General Introduction                      | 10   |
| 2.2.2             | The Central Executive                     | 11   |
| 2.2.3             | The Phonological Loop                     | 12   |
|                   | (a) The Articulatory Control Process      | 12   |
|                   | (b) The Phonological Short-Term Store     | 13   |
| 2.2.4             | The Visuo-Spatial Sketch Pad              | 14   |
| 2.3               | DEVELOPMENTAL CHANGES IN WORKING MEMORY   | 16   |
| 2.4               | COMPONENT READING SKILLS                  | 17   |
| 2.4.1             | Dual-Route reading model                  | 17   |
|                   | (a) Indirect or Nonlexical Reading Route  | 19   |
|                   | (b) Direct or Lexical Reading Route       | 19   |



|       |   |    |
|-------|---|----|
| 2.4.2 | Development of Component Reading Skills     | 21 |
|       | (a) Stages of Dual-Route Reading            | 21 |
|       | Development                                 |    |
|       | (i) Logographic Stages                      | 22 |
|       | (ii) Phonological Coding Stage              | 22 |
|       | (iii) Orthographic Stage                    | 23 |
|       | (b) An Alternative to Reading Stage         | 24 |
|       | Models                                      |    |
| 2.5   | WORKING MEMORY IN COMPONENT READING SKILLS  | 25 |
| 2.6   | WORKING MEMORY IN READING COMPREHENSION     | 27 |
| 2.6.1 | General Overview                            | 27 |
| 2.6.2 | A Working Memory Model of Reading           | 28 |
|       | Comprehension by W. Kintsch and Van Dijk    |    |
| 2.6.3 | Development of Reading Comprehension        | 31 |
| 2.7   | CONCLUSIONS                                 | 35 |
| 3.    | WORKING MEMORY MEASUREMENT IN RELATION TO   | 37 |
|       | READING                                     |    |
| 3.1   | INTRODUCTION                                | 37 |
| 3.2   | TRADITIONAL MEASURES OF WORKING MEMORY      | 37 |
| 3.2.1 | The Digit Span Test                         | 37 |
| 3.2.2 | Reading Retardation and Digit Span          | 38 |
| 3.2.3 | Other Traditional Span Tests                | 39 |
| 3.3   | TOWARDS IMPROVED MEASURES OF WORKING MEMORY | 40 |
|       | IN RELATION TO READING                      |    |
| 3.3.1 | Development of a Working Memory Span Test   | 40 |
| 3.3.2 | The Reading Span Test                       | 41 |
| 3.3.3 | The Working Memory Span Test                | 42 |
| 3.4   | OTHER STUDIES OF WORKING MEMORY AND READING | 47 |
|       | IN ADULTS                                   |    |
| 3.5   | WORKING MEMORY MEASURES AND READING IN      | 53 |
|       | CHILDREN                                    |    |

|       |   |    |
|-------|---|----|
| 3.5.1 | Working Memory and Reading Comprehension                                  | 53 |
| 3.5.2 | Working Memory and Component Reading Skills                               | 56 |
| 3.6   | PROBLEMS RELATING TO SUBJECT SELECTION IN<br>READING RETARDATION RESEARCH | 59 |
| 3.7   | CONCLUSIONS   | 60 |
| 4.    | AIM AND HYPOTHESES  | 62 |
| 4.1   | AIM   | 62 |
| 4.2   | HYPOTHESES  | 64 |
| 5.    | PILOT STUDY: METHOD, RESULTS AND DISCUSSION                               | 66 |
| 5.1   | INTRODUCTION  | 66 |
| 5.2   | METHOD  | 66 |
| 5.2.1 | Research Design   | 68 |
| 5.2.2 | Subjects  | 67 |
| 5.2.3 | Materials   | 68 |
|       | (a) Word Tests  | 69 |
|       | (i) Component Reading Skills  | 69 |
|       | (ii) Working Memory Span Tests  | 71 |
|       | (b) Sentence and Paragraph Tests  | 71 |
|       | (i) Reading and Language Tests  | 71 |
|       | (ii) Complex Working Memory Tests   | 72 |
|       | (c) Other Memory Tests  | 72 |
| 5.2.4 | Procedure   | 73 |
| 5.3   | RESULTS   | 82 |
| 5.4   | DISCUSSION  | 82 |
| 6.    | WORKING MEMORY IN READING : MAIN STUDY                                    | 85 |
| 6.1   | METHODS   | 85 |
| 6.1.1 | Research Design   | 85 |
| 6.1.2 | Subjects  | 85 |
| 6.1.3 | Materials   | 86 |

|       |   |     |
|-------|---|-----|
| 6.1.4 | Procedure   | 86  |
| 7.    | MAIN STUDY RESULTS  | 88  |
| 7.1   | INTRODUCTION  | 91  |
| 7.2   | STATISTICAL ANALYSIS OF RESULTS   | 91  |
| 7.2.1 | General Descriptive Statistics  | 91  |
| 7.2.2 | Correlations  | 100 |
| 7.2.3 | Regression Analyses   | 110 |
| 7.3   | SUMMARY OF RESULTS  | 112 |
| 8.    | DISCUSSION  | 117 |
| 8.1   | GENERAL OVERVIEW  | 117 |
| 8.2   | DISCUSSION OF WORKING MEMORY RESULTS                                      | 117 |
| 8.2.1 | Working Memory in Reading   | 117 |
|       | (a) Working Memory and Reading<br>Comprehension                           | 117 |
|       | (i) Complex Working Memory Tests  | 117 |
|       | (ii) Traditional Working Memory Tests                                     | 120 |
|       | (b) Working Memory and Component Reading<br>Skills                        | 122 |
|       | (i) Complex Working Memory Tests  | 122 |
|       | (ii) Traditional Working Memory Tests                                     | 123 |
|       | (c) Conclusions   | 126 |
| 8.2.2 | Working Memory in General   | 126 |
|       | (a) Relationships between Complex and<br>Traditional Working Memory Tests | 126 |
|       | (b) Relationships between Traditional<br>Working Memory Tests             | 128 |
| 8.3   | DISCUSSION OF READING AND LANGUAGE RESULTS                                | 129 |
| 8.3.1 | Component Reading Skills and Reading<br>Comprehension                     | 129 |

|       |  |     |
|-------|--|-----|
| 8.3.2 | Listening Comprehension and Vocabulary<br>in Reading | 131 |
| 8.4   | INTERGROUP DIFFERENCES                               | 132 |
| 8.4.1 | Intergroup Differences in Working Memory             | 132 |
| 8.4.2 | Intergroup Differences in Reading                    | 133 |
| 8.5   | IMPLICATIONS   | 137 |
| 8.5.1 | Introduction   | 137 |
| 8.5.2 | Working Memory and its Role in Reading               | 137 |
|       | (a) Phonological Loop and Reading                    | 137 |
|       | (b) Central Executive and Reading                    | 140 |
| 8.5.3 | Reading Development                                  | 143 |
| 8.5.4 | Working Memory Development                           | 145 |
| 8.5.5 | Other Factors affecting Reading<br>Comprehension     | 146 |
| 8.6   | FUTURE PROPOSED RESEARCH                             | 147 |
| 8.7   | OVERALL SUMMARY AND CONCLUSIONS                      | 148 |
|       | APPENDICES   | 151 |
|       | REFERENCES   | 178 |

## LIST OF FIGURES

| Page   |   |     |
|--------|---|-----|
| FIGURE |   |     |
| 1.     | The Atkinson and Shiffrin Model of Memory   | 2   |
| 2.     | The Current Model of Working Memory   | 11  |
| 3.     | A Model of Lexical and Nonlexical Reading Routes  | 18  |
| 4.     | Stage Models of Reading Development   | 21  |
| 5.     | The W. Kintsch and van Dijk Model of Processing<br>Stages in Comprehension  | 29  |
| 6.     | Mean Stanines on the Reading Comprehension Test<br>in the Pilot Study   | 83  |
| 7.     | Developmental Changes in Results of the Silent<br>Tests of Phonology for Regular and Irregular<br>Word and Nonword Rhyming Judgements | 94  |
| 8.     | Developmental Changes in Results of the Lexical<br>Decision Tests of Orthography  | 95  |
| 9.     | Developmental Changes in Results of Non-<br>pseudohomophone and Pseudohomophone Lexical<br>Errors                                     | 96  |
| 10.    | Developmental Changes in Results of the Complex<br>Working Memory Reading and Listening Span Tests                                    | 98  |
| 11.    | Developmental Changes in Results of the Digit,<br>Word and Dot Counting Span Tests  | 100 |

## LIST OF TABLES

Page

TABLE

|  |     |
|--|-----|
| 1. Subjects included in the Pilot Study  | 63  |
| 2. Mean Scores and Standard Deviations obtained<br>by Pilot Subjects on Reading and Language Tests   | 79  |
| 3. Mean Scores and Standard Deviations obtained<br>by Pilot Subjects on Working Memory Tests   | 81  |
| 4. Subjects included in the Main Study   | 85  |
| 5. Mean Scores and Standard Deviations obtained<br>by Subjects in Main Study for Reading and<br>Language Tests   | 91  |
| 6. Mean Scores and Standard Deviations obtained<br>by Subjects in the Main Study for Working<br>Memory Tests   | 97  |
| 7. Pearson Product-Moment Correlations :<br>Standard 1 Subjects  | 102 |
| 8. Pearson Product-Moment Correlations :<br>Standard 3 Subjects  | 103 |
| 9. Pearson Product-Moment Correlations :<br>Standard 5 Subjects  | 104 |
| 10. Pearson Product-Moment Correlations :<br>Standard 1, 3 and 5 Subjects Combined   | 108 |
| 11. Pearson Product-Moment Correlations :<br>Standard 1, 3 and 5 Subjects Combined,<br>Effects of Age Partialled Out on Component<br>Reading Skills and Working Memory Tests | 109 |

## CHAPTER 1

### BRIEF OVERVIEW

In recent years, cognitive psychologists have spearheaded human cognitive research. They use an information processing approach to understand the mental structures and operations involved in complex skills, such as memory and reading. The construct of information processing refers to a sequence of time-consuming cognitive activities occurring between the reception of an external stimulus and an observable response (Klatzky, 1980; Meyer, Osman, Irwin, & Yantis, 1988). The present research makes use of an information processing frame of reference to examine the developmental relationship between components of memory and reading.

Memory is crucial for effective everyday and higher cortical functioning (Lindsay & Norman, 1977). Human memory consists of a complex series of interconnected systems enabling storage and retrieval of information (Baddeley, 1982, 1990). These systems include sensory, and short- and long-term, memory (Lindsay & Norman, 1977, Baddeley, 1990). As the name implies, short-term memory provides temporary storage for information (Baddeley, 1982, 1990). Broadbent (1958) proposed the first information processing model of short-term memory. The model was later expanded to include a short-term "working" memory (Atkinson & Shiffrin, 1971) as illustrated in Figure 1. This working memory is for holding and manipulating material during various cognitive tasks, such as reasoning, mental arithmetic and reading (Baddeley, 1990; Klatzky, 1980), and

simultaneously transferring newly processed information to, and retrieving other information from, long-term memory. An example of retrieval from long-term memory when processing new material is accessing the meanings of words while reading. Nowadays, cognitive psychologists tend to use the term "working memory" rather than "short-term memory", as the latter depicts the information processing functions of this system more accurately (Waldron, 1987).

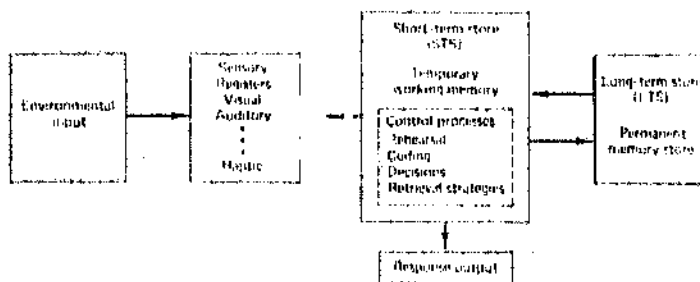


FIGURE 1

The Atkinson and Shiffrin model of memory. From Atkinson R.G., & Shiffrin R.M. (1971).

The sequential storage of printed words and the text-processing and -integrating functions required in reading comprehension in adults are attributed to working memory (Baddeley, 1984, 1986, 1990; Daneman & Carpenter, 1980). Models of reading comprehension using the working memory paradigm have been formulated using skilled adult readers as subjects (Bloom, Fletcher, van den Broek, Reitz, & Shapiro, 1990; Fletcher & Bloom, 1988; Kintsch & van Dijk, 1978; Just & Carpenter, 1980, 1987; van Dijk & Kintsch, 1983). In children, the role played by working memory in reading comprehension has been investigated by comparing disabled readers and normal controls matched for chronological and/or



reading ages (Ackerman, 1984; Jorm, 1983; Oakhill & Yuill, 1986; Yuill, Oakhill & Parkin, 1989). However, from a developmental point of view, little is known about the interaction between working memory and reading comprehension. Furthermore, developmental changes in the memory processes of poor readers need to be addressed (Jorm, 1983) as there is evidence of working memory deficits in these children (Brady, 1986; Torgeson, Rashotte, & Greenstein, 1988). These deficits appear to be language-based and to involve phonological coding, that is, the conversion of symbolic stimuli into sounds (Brady, 1986; Lieberman, Mann, Shankweiler, & Werfelman, 1982; Mann, 1984; Rack, 1985; Torgeson, Rashotte, & Greenstein, 1988).

There is, thus, a need to study the interaction between working memory, component reading strategies and reading comprehension from a developmental perspective. The present research attempts to address this need by modifying studies of Baddeley, Logie, Nimmo-Smith, and Brereton (1985), using adult subjects, for children at various stages of reading development.

A variety of memory and reading constructs are covered in this thesis, and the layout is as follows. Detailed theoretical backgrounds on working memory and reading theories are presented in chapter 2 with an emphasis on developmental aspects. Studies of working memory measures in relation to component reading skills and reading comprehension are reviewed in chapter 3. The aims of the current research and hypotheses are presented in chapter 4. These are followed by the pilot study, including methods, results and discussion, in chapter 5, and the methods used in the main study in chapter 6. The results of the main study are presented in chapter 7 and discussed in chapter 8.

## CHAPTER 2 THEORETICAL BACKGROUND

### 2.1 EVOLUTION OF THE WORKING MEMORY CONSTRUCT

#### 2.1.1 Hypothetical precursors

James (1890) described two forms of memory, namely, primary and secondary memory, which compare with recent views of short- and long-term memory respectively. The present-day construct of working memory evolved from early theories of short-term memory, such as those proposed by Broadbent (1958), Miller (1956), Brown (1958) and Peterson and Peterson (1959).

The idea of structural components in short-term memory was introduced by Broadbent (1958). His model of short-term memory comprised two subsystems. The "S" system briefly stored sensory information for processing by the limited capacity "P" system. This limitation appeared to prevent persons from attending to several sources of sensory input simultaneously. Miller (1956) shared the view of limited processing capacity and had previously postulated that a maximum of seven plus or minus two bits or chunks of information could be concurrently retained and processed by adults. Melton (1963) proposed a direct relationship between the number of chunks of information held in short-term memory and the rate of memory trace decay. Rehearsal, or the repetitive articulation of verbal material, was essential for short-term retention according to Brown (1958) and Peterson and Peterson (1959). They showed that the prevention of rehearsal, using an interference technique called articulatory suppression, resulted in

forgetting due to memory trace decay.

### 2.1.2 More Recent Hypotheses: Modal Models

Computer technology and cognitive psychology provided the analogy of short-term memory acting as a controlling executive system "because ... the processes carried out ... are under the immediate control of the subject and govern the flow of information in the memory system" (Atkinson & Shiffrin, 1971, p. 82). This line of thought culminated in modal models of memory based on modality specific sensory registers and common short- and long-term stores (Hitch, 1980). These models posited that only information held and processed in the short-term store would pass into long-term memory (Baddeley, 1982). Short-term retention was improved by control processes including rehearsal, as described by Brown (1958) and Peterson and Peterson (1959), imaging (the use of visual images to recall verbal material) and coding (Atkinson & Shiffrin, 1971).

Coding could adopt two forms. Firstly, material could be altered to facilitate recall by adding easily retrievable information, such as mnemonic phrases (Atkinson & Shiffrin, 1971). Secondly, material from different sensory input modes could be translated into a form that could be stored in short-term memory (Levy, 1971). Conrad (1964) and Wickelgren (1965, 1966) provided evidence of coding in short-term memory. Their analyses of recall error patterns during short-term listening tasks revealed acoustic (sound-related) and articulatory (speech related) coding respectively. Murray (1967) found that visually presented material was coded into an acoustic form using overt or covert articulation to ensure compatibility with the acoustic qualities of short-term memory. Auditorily presented

material was already in an acoustic form and, therefore, did not require coding. Levy (1971) investigated articulatory and acoustic coding and also revealed that both acoustic and articulatory codes were used in short-term memory.

According to modal models, short-term memory was involved in a variety of cognitive tasks, including solving problems (Hunter, 1964), comprehending language (Rumelhart, Lindsay, & Norman, 1972) and long-term learning (Atkinson & Shiffrin, 1968; Waugh & Norman, 1965). Thus, short-term memory was no longer viewed as a passive short-term store, but rather as a system actively involved in processing information during higher cognitive functions.

### 2.1.3 Criticism of Modal Models

Despite contributing towards an understanding of human memory, modal models could not explain certain research findings (Baddeley, 1986, 1988, 1990; Eysenck, 1988; Hitch, 1980). For example, according to these models, transfer of information into long-term memory was mediated by the short-term store (Hitch, 1980). Neuropsychological evidence from brain-injured patients with memory deficits did not always concur with this assumption. In some brain-injured patients, long-term memory was preserved in spite of impaired short-term memory (Shallice & Warrington, 1970). In others, however, an intact short-term memory failed to produce new, long-term learning (Milner, 1966).

Research into the assumptions that rehearsal and prolonged retention of information in short-term store resulted in long-term learning also produced controversial findings ( Craik & Watkins, 1973; Tulving,

1966). The findings showed that rehearsal maintained information in short-term store both with and without long-term learning taking place. Moreover, the extent of long-term learning was not directly proportional to the length of time information had been held in short-term memory.

That there were clear-cut differences between short- and long-term memory coding was also questioned. Modal models suggested that phonological or acoustic codes were used in short-term memory, and semantic codes, in long-term memory (Baddeley, 1986, 1990). However, evidence existed of phonological and semantic coding in both short- and long-term memory (Bruce & Crowley, 1970; Shulman, 1970). Visual coding also occurred in short-term memory (Kroll, Parks, Parkinson, Bieber, & Johnson, 1970). With reference to their "levels of processing" memory model, Craik and Lockhart (1972), postulated that coding methods depended on the type of processing task and available resources rather than the site where coding occurred. Unfortunately, their model concentrated on long-term memory and failed to offer an alternative framework for a revised hypothesis of short-term/working memory (Baddeley, 1986).

Although modal models assigned short-term memory "... the role of an operational or working memory, the empirical evidence for such a view ... (was) remarkably sparse" (Baddeley & Hitch, 1974, p. 48). Thus, modal models viewed short-term memory as a conduit for carrying information from sensory memory into long-term memory. Some researchers felt that this down-graded view was unacceptable, and that a revised and more comprehensive model of short-term memory was necessary. This led Baddeley and Hitch (1974) to undertake a detailed investigation of short-term memory functions.

#### 2.1.4 Towards a Model of Working Memory

Baddeley and Hitch (1974) used an information processing approach to investigate short-term memory and aimed to formulate a working memory hypothesis. They tested the postulated "limited capacity" of short-term memory by manipulating factors that might compete for storage and processing space during reasoning, comprehension and free recall tasks. They experimentally manipulated the capacity of the system by overloading it, by increasing the difficulty in phonological discrimination and by interfering with subvocal rehearsal (articulatory suppression). They found:

- i. Preloads of two or more items appeared to have little effect, whereas six items retarded verbal processing.
- ii. Phonemic similarity (referring to similar sounds in words) appeared to interfere with phonological coding, resulting in reasoning, comprehension and free recall errors.
- iii. Repeating irrelevant words or random digit sequences while performing other tasks appeared to impede verbal processing. This was particularly so for digits.

In general, the results showed a trade-off between the space required for storage and the processing rate for concurrent tasks. However, the method of allocation of this space was unclear. Baddeley and Hitch concluded that a common system or limited capacity "work space" was responsible for storage and control processing functions. A passive phonemic response buffer and an

active articulatory component seemed to operate in conjunction with this work space. This buffer and articulatory component were combined to form a "phonemic rehearsal buffer component" (p. 86). A visual short-term memory component was later introduced to accommodate evidence of visual images that lasted longer than icons (Baddeley, 1976; Phillips & Christie, 1977a, 1977b).

In addition to the phonemic rehearsal buffer component (Baddeley & Hitch, 1974), further findings indicated a phonemic store that did not rely on articulation (Baddeley, 1981; Baddeley & Lewis, 1981). This was evident when articulatory suppression failed to disrupt homophone judgements of visually presented words (Baddeley & Lewis, 1981). Besner and Davelaar (1982) also reported two phonological codes that responded to print, one of which was not affected by articulatory suppression. Baddeley and Lewis (1981) referred to them as the "inner voice" and the "inner ear". Thereafter, Salame and Baddeley (1982) suggested dividing the phonemic rehearsal/buffer component into a phonemic store and an articulatory component. Vallar and Baddeley (1984) supported this suggestion following their assessment of a brain-injured patient with an auditory verbal short-term memory deficit. They found distinct phonemic similarity effects (associated with phonemic coding and retention) in the absence of significant word length or articulatory suppression effects (associated with speech or phonological coding). Therefore, separate components appeared to be responsible for phonemic- and speech/phonological coding respectively. A model of working memory was proposed based on these findings.

## 2.2 A MODEL OF WORKING MEMORY

### 2.2.1 General Introduction

Working memory was defined as "... a system for the temporary holding and manipulation of information during the performance of a range of cognitive tasks such as comprehension, learning, and reasoning" (Baddeley, 1986, p. 34). The first working memory model suggested a central processing unit, the central executive, which received input from the senses and controlled or directed activities in two slave systems, the articulatory loop and the visuo-spatial scratch pad (Baddeley, 1981). Apart from retention and information-processing functions, the central executive was capable of activating information in, and transferring encoded information to, long-term memory. This model was revised in accordance with the proposal to divide the articulatory loop into two systems (Salame & Baddeley, 1982) based on neuropsychological evidence (Vallar & Baddeley, 1984) as discussed in 2.1.4. The revised model had three slave systems, the articulatory loop, the primary acoustic short-term store and the visuo-spatial scratch pad. These slave systems represented the articulatory component and the phonemic and visual short-term stores respectively (Baddeley & Hitch, 1974; Vallar & Baddeley, 1984).

The current model also has a central executive, but has reverted to two slave systems, the phonological loop and the visuo-spatial sketch pad (Baddeley, 1986, 1990; Gathercole & Baddeley, 1989, 1990). The phonological loop comprises two components, a phonological short-term store and an articulatory control process. Although the names of some of the slave system have changed, they retain the same functions. This should be borne in mind when reading literature on working memory



as the terminology may vary depending on the author.

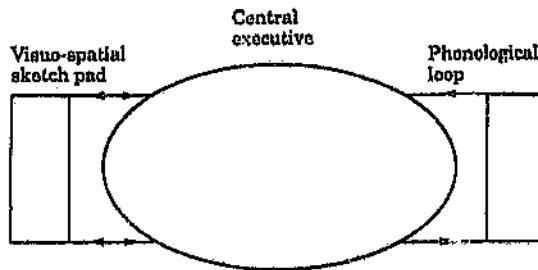


FIGURE 2

The Current Model of Working Memory. From Baddeley, A.D. (1990).

### 2.2.2 The Central Executive

The central executive is the limited capacity work space proposed by Baddeley and Hitch (1974). The structure and way in which it carries out its functions are still under investigation. However, it appears to be involved in all activities requiring attention (Baddeley, 1981, 1990; Eysenck, 1988). As the word "executive" suggests, it is involved in planning, controlling and carrying out behaviour. These executive functions resemble those attributed to the "supervisory activating system" (SAS) in a model of attention by Norman and Shallice (1986). Executive functions are the produce of the frontal lobes according to neuropsychological theories regarding brain structure and behaviour relationships (Lezak, 1983). Working memory (central executive) planning, tracking and self-monitoring functions during a visuospatial task have been found to be significantly poorer in patients with frontal lobe lesions (Owen, Downes, Sahakian, Polkey, & Robbins, 1990). The possibility that the central executive is associated with the frontal lobes has also

been raised in the light of deficits observed in Alzheimer patients (Baddeley, 1986, 1988, 1990). These patients have difficulty in tracking and in integrating two or more cognitive operations when performing tasks.

The central executive is also involved in storage and processing. To this end, it coordinates working memory operations and the flow of information between itself, the slave systems and long-term memory (Baddeley, 1988, 1990). Information-processing tasks in which the central executive appears to play an important role include reading comprehension. This is discussed in 2.7.

### 2.2.3 The Phonological Loop

In Baddeley's most recent model of working memory (1990), the phonological loop incorporates an acoustic storage system, the phonological short-term store or memory, and an articulatory component, the articulatory control process. Input to the phonological loop occurs via acoustic images and auditory or subvocal speech. Both phonemic and phonological coding occur in this loop. The resultant representations are then stored in the phonological short-term store. According to Baddeley, the issue of whether the articulatory component and the phonological short-term store should be seen as two separate systems or as components of a single system is a "moot point" (Baddeley, 1986, p. 86) at this stage in his research into working memory.

#### (a) The Articulatory Control Process

The articulatory control process comprises the inner speech component and output buffer responsible for articulatory coding or rehearsal in short-term memory,

and phonological coding and subvocalization in reading (Baddeley, 1990; Baddeley, Eldridge, & Lewis, 1981). It works in close collaboration with the phonological short-term store. Auditory memory traces in this store are refreshed by subvocal rehearsal in the articulatory control process and then transferred back to the phonological short-term store. Visual input may also be phonologically encoded, rehearsed and retained in this way.

The articulatory control process rehearses auditory information to be processed by the central executive, thereby facilitating transfer to, and retrieval from, long-term memory (Dempster, 1981). In this context, it works together with the phonological short-term store in contributing to the acquisition and retention of new words in a person's vocabulary (Baddeley, 1990; Gathercole, 1990; Gathercole & Baddeley, 1989). It also operates during memory span tasks. However, its output capacity is restricted to the number of syllables that can be articulated during a two-second period (Baddeley, 1990; Eysenck, 1988). This produces the word-length effect, whereby one's memory span for short words is greater than that for long words (Baddeley, 1990; Baddeley, Thompson, & Buchanan, 1975). Short-term auditory recall may also be impaired by articulatory suppression (Baddeley, Lewis, & Vallar, 1984; Christowitz, Doctor, & Saling, 1985).

#### (b) Phonological Short-term Store

The phonological short-term store or memory acts as an auditory input register and temporary store for auditory information (Baddeley, 1990; Baddeley, Lewis, & Vallar, 1984; Hitch, 1980; Vallar & Baddeley, 1984). It operates by means of an acoustic or phonemic code,

which is not affected by articulatory suppression. It seems to be responsible for the recency effect during free recall tasks whereby the items presented last are recalled first. This effect disappears with time delays (Hitch, 1980). Auditory memory traces can be retained for longer periods by means of rehearsal in the articulatory control process.

One of the phonological short-term store's most important functions appears to be related to spoken and written language comprehension (Baddeley & Wilson, 1988). Entire sentences, or parts thereof, are maintained in this store during processing. This occurs with long, syntactically complex sentences that cannot be processed immediately (Vallar & Baddeley, 1984). Impairment of this store following brain injury may adversely affect the ability to understand speech, and to a lesser extent, written language.

#### 2.2.4 The Visuo-Spatial Sketch Pad

Visuospatial and -sequential stimuli appear to be temporarily retained and manipulated in the visuo-spatial sketch pad (Baddeley, 1986, 1990). There is also evidence of a passive, visuo-perceptual input store, similar to the phonological short-term store. Eye movements may play a role in refreshing visual memory traces similar to that of articulation in the articulatory control process. This pad may be involved in the visual memory aspects of reading, such as the sequential retention of letter strings (Baddeley, 1986).

In summary, the current model of working memory consists of the central executive, a phonological loop,

comprising the articulatory control process and phonological short-term store, and the visuo-spatial sketch pad. As there is ongoing research into the working memory model, the structures and terminology may change. However, components of working memory, in particular the central executive and the phonological loop, appear to play an active role in reading. This is discussed in 2.6 and 2.7.

### 2.3 DEVELOPMENTAL CHANGES IN WORKING MEMORY

Three views have been proposed regarding developmental changes in working memory capacity. The first suggested that the number of central executive memory slots (processing space) increased with age until adulthood (Huttenlocher & Burke, 1976) when seven plus or minus two memory slots were available to simultaneously process the same number of bits of information (Miller, 1956). Disparate findings, however, indicated little change in the number of memory slots per se from about five years of age (Chi, 1976) resulting in the second view. According to this view, working memory performance did not improve as a result of increased capacity. Instead, the use of more effective central executive processing skills or strategies enabled the child to handle more bits of information at one time (Perfetti & Lesgold, 1977). The third view (Case, Kurland, & Goldberg, 1982) was between the other two and suggested that efficiency in using processing skills developed relative to the amount of attention required by the processing. The latter was reduced as processing skills became more automatic (Case, 1985), thereby increasing storage space and what might be termed "functional capacity".

Aspects of these developmental views can be applied to the working memory model. According to Baddeley (1986), working memory development could be explained in two ways. Firstly, available storage space in the central executive might increase as the demand for the limited attentional capacity decreased with more efficient use of memory strategies or control processes. Memory strategies can be defined as, "... cognitive or behavioural activities that are under the deliberate control of the subject and are employed to enhance memory performance" (Naus & Ornstein, 1983, p. 12). Rehearsal in the articulatory loop and chunking can be regarded as memory strategies.

The other explanation centred on an improvement in the rate of articulation or subvocalization associated with speech development without specific reference to the central executive (Baddeley, 1986). From the age of five years, children appeared to make increasing use of covert speech or rehearsal to aid memorization (Conrad, 1971; Ornstein, Naus, & Liberty, 1975; Torgeson & Goldman, 1977). However, the use of this strategy was not as spontaneous in young children as it was in older children (Guttentag, 1985; Harris, 1978; Kail, 1979). Older children adopted active rehearsal strategies compared with passive strategies in younger children (Ornstein, Medlin, Stone, & Naus, 1985). This allowed them to combine a greater number of memory items together (Kunzinger, 1985; Ornstein, Naus, & Liberty, 1975), thereby increasing their rehearsal set sizes. Thereafter, their rehearsal sets contained more early list items (primacy effect) at the expense of later items (recency effect) during memory span tasks. Deficits in active rehearsal strategies resulted in lower primacy effects in learning disabled children (Bauer, 1977, 1979). Active strategies alone, however,

might not account for developmental differences in working memory (Huttenlocher & Burke, 1976). Changes in the speed of item identification and phonetic encoding also appeared to be involved (Lorsbach & Gray, 1986; Spring, 1976; Spring & Capps, 1974).

Baddeley (1986) postulated that the articulatory control process in the phonological loop was implicated in memory span development for auditorily presented material. Children's articulatory skills appeared to improve with age due to central nervous system maturation and/or practice. The rate of subvocal rehearsal was thereby increased, enabling more material to be held in the phonological short-term store. The phonological loop also appeared to be involved in visual memory development. However, visually presented material had to be named and the name rehearsed to ensure retention (Baddeley, 1986). As stated, the spontaneous use of these strategies increased with development (Guttentag, 1985; Harris, 1978; Kail, 1979).

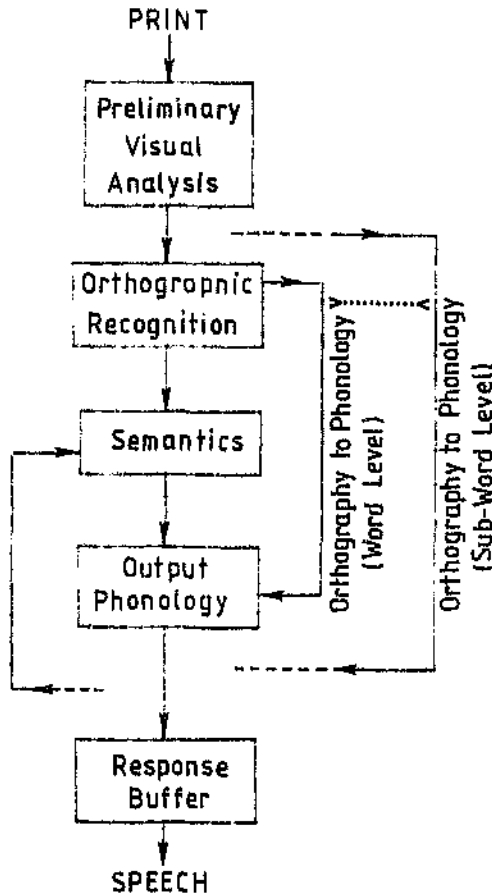
Thus, the central executive and phonological loop components of working memory show developmental trends in children. Both these components are involved in cognitive tasks, including reading. This raises the question of whether there is a reciprocal relationship between working memory and reading development and this is discussed after structural and developmental models of component reading skills are considered.

## 2.4 COMPONENT READING SKILLS

### 2.4.1 Dual-Route Reading Model

Reading requires the integration of visual and verbal subcomponent skills (Bowers, 1988). In reading, printed

text is decoded and assimilated with existing knowledge to promote comprehension. According to Harris and Coltheart (1986), there are two mental procedures involved in decoding printed words, namely phonics and whole-word procedures. These are shown in Figure 3.



**FIGURE 3**

A model of lexical and nonlexical reading routes. From Patterson, K.E., Marshall, J.G., and Coltheart, M. (1985).



### (a) Indirect or Nonlexical Reading Route

The phonics procedure involves the indirect or nonlexical reading route utilizing the correspondence between speech and reading (Friedman & Albert, 1986). This route employs letter-sound or grapheme-phoneme correspondence or conversion rules for reading familiar, regular words in young children, and unfamiliar, regular words in older children and adults (Harris & Coltheart, 1988, Morton & Patterson, 1980). Letter strings are segmented into single letters or syllables. These are converted into sounds, which are then blended to form words (Bryant & Goswami, 1987). Nonwords can be read in the same way. Meanings can be accessed only if the words are in an individual's spoken vocabulary. Words can also be read by analogy to known words using this route (Marcel, 1980). For example, the word "HOUSE" can be read if the word "MOUSE" is known simply by substituting the initial letter-sound.

An important disadvantage of this route is the inability to read irregular words correctly. For example, if one applies letter-sound correspondence rules when reading the word "TONGUE", it would be pronounced "TONGEW". As skilled readers seldom mispronounce familiar irregular words, there is evidence for a direct or lexical reading route. This route enables readers to recognize whole words from their appearance without applying letter-sound correspondence strategies.

### (b) Direct or Lexical Reading Route

The whole-word procedure makes use of a direct or lexical reading route. During this procedure, printed

words are compared to visual representations, called lexical entries, in an individual's mental lexicon (Coltheart, Davelaar, Jonasson, & Besner, 1977; Harris & Coltheart, 1986). This mental lexicon resembles an internal dictionary. It contains separate subsystems for processing phonological, orthographic and semantic information belonging to lexical entries. Lexical access is the process whereby a visual word stimulus activates its semantic representation or meaning in the semantic subsystem.

Entries stored in the lexicon are word specific (Coltheart, 1985). Therefore, this route is used once the reader has learned, and can recognize, the direct relationship between a string of letters comprising a word, its articulation and its meaning. For example, the letter string "D O G" is read directly as "dog" and interpreted as a four-legged domestic animal that barks. This route is essential for reading irregular words (Harris & Coltheart, 1986). These words, for example, "YACHT", do not follow letter-sound correspondence rules. The lexical route is also used to discriminate between homophones or words with the same pronunciations, but different spellings and meanings, for example, "RED" and "READ" (Friedman & Alibert, 1985).

Evidence to support the dual-route model has come from studies of brain-injured patients exhibiting acquired dyslexias affecting one of the reading routes (Funnell, 1983; Patterson, 1981). In surface dyslexia, the lexical route is impaired and patients cannot read irregular words (Harris & Coltheart, 1986). In phonological dyslexia, patients can read familiar words lexically, but cannot read nonwords using letter-sound correspondence rules (Funnell, 1983).

## 2.4.2 Development of Component Reading Skills

### (a) Stages of Dual-Route Reading Development

Unlike learning to talk, reading does not develop spontaneously (Harris & Coltheart, 1986). Instead, a child is taught to read during the initial years of formal education. By that stage, he/she has large listening and spoken vocabularies (Ellis, 1984) corresponding to the input and output phonological lexicons. Research into reading acquisition has shown that children use dual-route reading strategies (Bradley & Bryant, 1983; Harris & Coltheart, 1986; Stuart & Coltheart, 1988) and, they are incorporated in most reading instruction programmes (Beech, 1987).

Some recent models propose that reading develops in a series of stages (Stuart & Coltheart, 1988) in which words are read via either the nonlexical or lexical routes. These include models by Frith (1985), Seymour and MacGregor (1984) and Harris and Coltheart (1986). Frith and Seymour and MacGregor classified reading development into three stages, whereas Harris and Coltheart described four stages. These models are illustrated in Figure 4.

| READING ROUTE       | Lexical                 |                          | Nonlexical                  | Lexical             |
|---------------------|-------------------------|--------------------------|-----------------------------|---------------------|
| READING STRATEGY    | Visual Feature Analysis |                          | Phonological Coding         | Orthographic Coding |
| MODEL 1             |                         |                          |                             |                     |
| Harris & Coltheart  | Sight-Vocabulary Stage  | Discrimination-Net Stage | Phonological-Recoding Stage | Orthographic Stage  |
| Frith               | Logographic Stage       |                          | Alphabetic Stage            | Orthographic Stage  |
| Seymour & MacGregor | Logographic Stage       |                          | Alphabetic Stage            | Orthographic Stage  |

FIGURE 4

Stage models of Reading Development.

### (i) Logographic Stages

A precursor to lexical reading involves logographic or visual feature analysis. Logographic word recognition is based on a few visual cues and relies on visual memory (Seymour, 1987). Phonology and pronunciation are recalled only after the word has been recognized. Single, unfamiliar words are not attempted and contextual cues are used to identify unfamiliar words in sentences.

Harris and Coltheart (1986) proposed two logographic reading stages, the first of which is the sight-vocabulary stage. This stage lasts until about five years of age during which time a child can read a small number of words directly. These words are acquired either spontaneously, such as brand names like Coca Cola, or by whole-word teaching methods. The second stage is the discrimination-net stage, which occurs during the first months of formal reading tuition and corresponds to an increase in reading vocabulary. During this stage, a child reads by means of partial visual cues, such as word length and individual letters. Therefore, he/she may incorrectly identify all long words as "television" because it is the only long word he/she knows. Frith (1985) and Seymour and MacGregor (1984) proposed only one early reading stage, the logographic stage. This stage incorporates the visual feature reading strategies described in both sight-vocabulary and discrimination-net stages.

### (ii) Phonological Coding Stage

Development of phonological skills seems to follow a pattern (Bryant & Goswami, 1987). At an early age, children understand the concept of rhyme or similar

sounding syllables in words, which enables preschool children to play rhyming word games (Stuart, 1987). Thereafter, they learn to separate words into the initial consonant or consonant clusters, called the "onset", and the remaining vowels plus final consonant, called the "rime" (Bryant & Goswami, 1987, Treiman, 1985, 1987). The ability to analyse and segment a word into all its component sounds or phonemes appears later when children learn the rules governing the correspondence between these sounds and alphabetic letters. The grapheme-phoneme correspondence rules are acquired during the early years of schooling, otherwise referred to as the phonological-recoding stage by Harris and Coltheart (1986) and the alphabetic stage by Frith (1985) and Seymour and MacGregor (1984). During this stage, children use the indirect or nonlexical reading route.

Grapheme-phoneme correspondence knowledge, however, may not be sufficient for word reading (Lieberman, Shankweiler, Fischer, & Carter (1974). Children must attain a conscious level of phonemic awareness. This implies mastery of higher phonological skills, including sequential decoding strategies and the mapping of segmented phonemes onto the pronunciation of a word (Cataldo & Ellis, 1988). Otherwise, a series of phonemes would be pronounced as a meaningless sound string. For example, "CAT" would be read as "CUHATUH". Further development in phonological coding skills allows children to read nonwords (Cataldo & Ellis, 1988).

### (iii) Orthographic Stage

The lexical reading route develops orthographically (Seymour, 1987). This involves reading whole words by

recognizing letters in a specific sequence according to spelling rules (Harris & Coltheart, 1986). Visual representations of words stored in the lexicon enable this direct word recognition.

The orthographic stage (Frith, 1985; Harris & Coltheart, 1986; Stuart & MacGregor, 1984) gradually replaces phonological coding for reading familiar words from about eight to ten years of age. By then, a child can visually identify familiar, whole regular and irregular words directly from the way in which they are spelt. This increases reading speed and heralds "... a bypass of phonological recoding in favour of visually mediated access" (McCusker, Hillinger, & Bias, 1981, p. 235). The number of words that can be recognized directly increases with the development of a child's word-specific knowledge.

#### (b) An Alternative to Reading Stage Models

According to Stuart and Coltheart (1988), stage models of reading development are inaccurate in assuming that "... all children pass through the same stages in the same order" (p. 149). They performed a longitudinal study of phonological and letter-sound knowledge on children before and during initial reading tuition. Their results showed that those children who could sequentially segment words into phonemes (phonemic segmentation) and who knew letter sounds started reading at the alphabetic or phonological-recoding stage rather than at the visually oriented logographic or discrimination-net stage. Only children who had not developed phonological skills initially made use of visual memory skills when learning to read.

Thus, reading is a complex skill involving both nonlexical and lexical component strategies. These strategies appear to develop in stages, although the stages may not be identical for all children. As mentioned before, working memory appears to be involved in reading. In the following section, the role played by working memory in the component reading strategies or skills will be discussed.

## 2.5 WORKING MEMORY IN COMPONENT READING SKILLS

The phonological loop may be involved in reading during the alphabetic (Frith, 1985; Seymour & MacGregor, 1984) or phonological-recoding (Harris & Coltheart, 1986) stage when children acquire and use letter-sound correspondence knowledge to read unfamiliar words (Gathercole, 1990). The articulatory control process may be the site where visually presented letter strings are phonologically recoded (Baddeley, Vallar, & Wilson, 1987). Each resultant phoneme is articulated in the articulatory control process and temporarily stored in the phonological short-term store while subsequent letters are being recoded. These phonemes are then blended into words (Baddeley, 1986, Wagner, 1988).

This early stage of reading occurs when most words are unfamiliar and phonological coding is important for lexical access and reading comprehension (Daneman, 1987). It may also contribute towards long-term learning of phoneme-grapheme correspondences (Ellis, 1990; Gathercole, 1990). Daneman (1987) postulated that although the phonological loop may not be involved in everyday fluent reading, adults also use phonological coding "... for identifying unfamiliar or new words" (p. 68).

In addition to inefficient phonological coding, poor immediate phonological memory may also impair reading. Brady (1986) found these disabilities to be interrelated in children who were poor readers. Their inefficient coding reduced available short-term memory capacity. Gathercole and Baddeley (1990) reported similar findings when comparing language disordered children with controls matched for verbal and nonverbal abilities. Development of phonological coding skills in the subject group was comparable to those of the younger verbal controls. However, they performed significantly poorer than both control groups on list-learning tasks, and Gathercole and Baddeley (1990) postulated a selective phonological short-term memory deficit in these language-disordered children. A longitudinal study of children with specific reading disabilities indicated phonological discrimination and processing difficulties, and auditory digit, and word and sentence span deficits (Ellis & Large, 1987).

The phonological loop, therefore, appears to play an active role in reading, particularly during the phonological recoding stage when grapheme-phoneme strategies are used to decode printed words. However, most interest in the relationship between working memory and reading has been focused on comprehension. Models of reading comprehension are generally based on studies of mature readers and are not concerned with developmental issues. However, the model of reading comprehension involving working memory, presented in the next section, has been used to investigate reading comprehension in children from a developmental perspective in previous studies. Reading comprehension development is discussed after the model has been presented.



## 2.6 WORKING MEMORY IN READING COMPREHENSION

### 2.6.1 General Overview

Written material is processed at word, sentence and text levels during comprehension (Colley, 1987). These processes include decoding and lexical access (word), segmentation, semantic and syntactical analyses and interpretation (sentence) and integrating sentences, recognizing and classifying the topic and activating relevant long-term knowledge (text) (Haberlandt & Graesser, 1985). Words in sentences are related to other information from preceding passages in the text as well as to a general frame of reference (Carpenter & Just, 1977).

Most information processing models of reading comprehension (Bloom, Fletcher, van den Broek, Reitz, & Shapiro, 1990; Fletcher & Bloom, 1988; Kintsch & van Dijk, 1978; Just & Carpenter, 1980, 1987; van Dijk & Kintsch, 1983) share common features. They describe underlying reading processes as well as how information and knowledge are represented. A mental representation of acquired knowledge is called a schema (Just & Carpenter, 1987), which is a framework consisting of discrete slots containing relevant information. There are slots for each structural component of a story, for example, the setting, plot, and resolution. They act as filing systems and allow for the organization of material during reading of the story. A schema also relates to other schemata in long-term memory.

Linguistic and conceptual information can be represented in units called propositions (Just & Carpenter, 1987). A proposition consists of a predicate and one or more concepts called arguments (Kintsch, W., Kozminsky, Streby, McKoon, & Keenan, 1975; Kintsch, W.

& van Dijk, 1978). Arguments comprise nouns and pronouns. Predicates are verbs, adverbs, adjectives and conjunctions and denote properties of, or relations between, arguments.

The W. Kintsch and van Dijk model (1978) is an information processing model of reading comprehension involving working memory. It uses schema- and text-based approaches to discourse structure and comprehension. This model is widely used as a basis for understanding the role played by working memory in reading comprehension in both adults and children.

#### 2.6.2 A Working Memory Model of Reading Comprehension by W. Kintsch and Van Dijk

The W. Kintsch and van Dijk model (1978), revised by van Dijk and W. Kintsch (1983), describes text comprehension as "... a cyclical process constrained by the limitations of working memory" (p. 363, 1978). This model, illustrated in Figure 5, adopts a parallel processing framework whereby reading is seen as an interactive process within the context of a schema as explained before. The schema refers to expectations regarding the structure of a story (Kintsch, W., 1977). Readers formulate the semantic structure of reading material according to their schema prior to attaining comprehension. Semantic structure includes a micro- and macrostructure, which are linked by semantic mapping rules or macrorules. The microstructure consists of propositions or semantic units in a text called the text base. The macrostructure or gist refers to high-level relationships between propositions as well as inferences made about these relationships (Kintsch, W. & van Dijk, 1978; van Dijk, 1977; van Dijk & Kintsch, W., 1983).

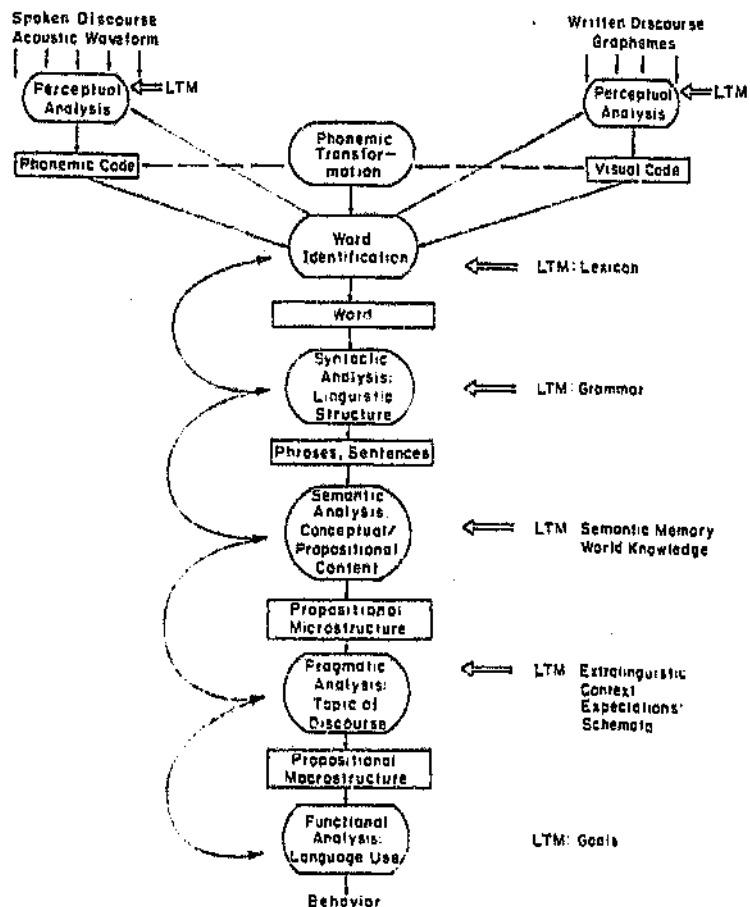


FIGURE 5

The W. Kintsch and van Dijk Model of Processing Stages in Comprehension. From Kintsch, W. (1977).

Both micro- and macrostructures are composed during simultaneous information processing cycles and storage in working memory. The sequence of operations involved in comprehension, both top-down (schematic) and bottom-up (from cues in the text), are illustrated in Figure 5 and are self-explanatory. At the microstructure level, activated semantic representations of words are held in

working memory and then grouped (chunked) into meaningful propositions. These propositions are then arranged in a coherent, hierarchical sequence, which forms the text base. Certain pertinent propositions are selected from earlier text material and held in the working memory buffer. Their purpose is to connect incoming chunks of text with already processed material if there are overlapping or common arguments. When commonalities occur, the incoming text is considered coherent with the text base, and is retained in long-term memory for integration at macrostructure level to form the gist. Irrelevant propositions are deleted and replaced by inferred propositions consistent with the schema.

A reader is, therefore, continually comparing incoming material with the selected, newly processed propositions, that are stored in the buffer to establish associations with previously processed reading material. Any proposition may be processed more than once, thereby increasing the likelihood of recall. Individual differences in text processing are due to buffer capacity, speed of processing and the complexity of the text (Kintsch, W. & van Dijk, 1978; van Dijk, 1977; van Dijk & Kintsch, W., 1983). In addition, prior knowledge of, or familiarity with, material in texts facilitates chunking and simultaneous processing of greater amounts of information.

The Kintsch and van Dijk model refers directly to the limited storage and simultaneous processing functions of working memory. Evidence supporting this model was obtained by manipulating text structures, such as the number of arguments in propositions and the number, and length, of propositions, and recording the changes in text reading rate and recall (Kintsch, W. & Keenan,

1973; Kintsch, W. et al., 1976; Manelis & Yekovich, 1976; McKoon, 1977). The results showed firstly, that processing time for propositions depended on the length of the text. The longer the text and the more numerous the propositions, the greater the time required for integrating those propositions. Secondly, in texts with identical numbers of words and propositions, those with several arguments in the propositions took longer to read and were harder to recall than those with fewer arguments. The more numerous arguments, which contained important content information, probably required more storage capacity in working memory, thus reducing processing capacity.

These studies refer to research results based on adult subjects. A selection of studies using the W. Kintsch and van Dijk model in the investigation of the development of reading comprehension in children is discussed in the next section.

### 2.6.3 Development of Reading Comprehension

The organization of story material for reading and listening comprehension purposes depends on available schemata, according to the W. Kintsch and van Dijk (1978, 1983) model. Although schemata were thought to be present primarily in older children, there is evidence of schematic micro- and macrostructural processing, both occurring in working memory, in young children. W. Kintsch (1977) found that 4-year-olds could organize random and sequentially ordered pictures into stories according to schemata. These children also inferred relevant propositions from the stories as a whole at the microstructure level. Furthermore, only relevant details were included for gist (macro-structure) recall. Thus, prereaders use both micro- and

macrostructural processes when listening to stories. Nevertheless, differences in working memory processing and storage capacity were found to contribute towards differences in listening comprehension in prereaders (Daneman & Blennerhassett, 1984).

Several studies have showed differences between reading comprehension in beginner and more experienced readers (Keenan & Brown, 1984). The differences were generally ascribed to developmental changes and improvement in decoding skills (Lomax, 1983). Although these skills contribute towards fluent reading, qualitative developmental changes in the comprehension process per se have not been noted (Keenan & Brown, 1984). Keenan and Brown (1984) replicated some of the work done by W. Kintsch and Keenan (1973), W. Kintsch et al (1975), Manelis and Yekovich (1976) and McKoon (1977) (see 2.7.2) in third- and fifth-grade readers. They measured reading times and recall after manipulating the number of arguments in propositions and the number and position of propositions in texts. Their findings are important for understanding reading comprehension development in children.

Firstly, they postulated that quantitative differences in reading times between third- and fifth-grade readers represented differences in the time taken to decode print and analyse syntax. Decoding and syntactical analyses relate directly to functions performed in the phonological loop. According to Baddeley, Vallar, and Wilson (1987), decoding can be attributed to the articulatory control process, whereas the phonological short-term store contributes towards syntactical analysis. This store "... acts as a 'mnemonic window', holding sequences of incoming discourse, and allowing the components of such sequences to be processed and

interrelated" (p. 526 - 527). The number of items or chunk size retained in the window is important for syntactical analysis. The more complex a sentence is syntactically, the more material has to be stored simultaneously for the sentence to be syntactically analysed and understood. Of relevance to working memory development is that younger children may be restricted in the number of items they can retain in order to analyse syntax.

Secondly, there were no differences in the way third- and fifth-grade readers constructed semantic meaning from text or in the hierarchical connections between these semantic units (microstructural processing). Reading times increased in both groups as the number of propositions per sentence increased, and recall of a proposition was contingent on its position in the hierarchy for both subject groups. Keenan and Brown (1984) concluded that children of various ages extract meaning from text in a similar way. This may be due to the fact that all children have considerable experience in oral language or listening comprehension before learning to read, and that listening comprehension correlates significantly with reading comprehension (Daneman & Blennerhassett, 1984; Palmer, MacLeod, Hunt, & Davidson, 1985). However, when comparing quantitative reading and listening comprehension results in younger and older children, reading comprehension may lag behind listening comprehension in the younger children (Durrell & Hayes, 1970).

Thirdly, there may be differences in macrostructural processing, that is "... in inferencing, generalizing and integrating the presented text with existing knowledge structures" (Keenan & Brown, 1984, p. 1568). There is evidence of developmental trends in

macrostructural processing (E. Kintsch, 1989). Older children are better able to make inferences from text and this improves comprehension and subsequent recall (Paris & Upton, 1976). Furthermore, children with developmental reading disabilities have greater difficulty making inferences than age-matched normal readers (Oakhill, 1984). These developmental trends may be ascribed to increased proficiency in lower-level processes, such as decoding and syntactical analysis. This lowers the demand on the limited working memory capacity for these functions, and makes more space available for higher-level processing (Perfetti, 1986). The higher-level processing functions resemble those performed by the central executive in working memory. This raises the possibility that macrostructural processes occur in the central executive. Research into the role played by the central executive in reading comprehension in children supported the hypothesis of a single, central processor (Yuill, Oakhill, & Parkin, 1989). However, studies using adult subjects have led Daneman (1987) and Daneman and Tardif (1987) to postulate the presence of two separate processors, a verbal/symbolic processor and a spatial processor. These studies are presented in chapter 3.

In a later study, Keenan (1986) compared the ability of fourth- and sixth-grade readers to recall paragraphs containing few and many different arguments. In general, the younger children had difficulty recalling the many-argument paragraphs, although there were no significant differences between them and the older children in terms of processing time, lexical access and structure of text representation. Keenan postulated that these difficulties were the result of developmental differences in working memory capacity, which adversely affected the accessibility of text



microstructure for recall.

## 2.7 CONCLUSIONS

The working memory model (Baddeley & Hitch, 1974; Baddeley, 1990) has stimulated considerable interest in the role played by various working memory components in the development of language skills, especially component reading skills and reading comprehension. The phonological loop, consisting of the articulatory control process and the phonological short-term store, may be responsible for decoding and storage during nonlexical reading. The phonological short-term store may also be involved in the sequential storage of discourse necessary for listening and reading comprehension. The latter appears to occur during both nonlexical and lexical reading. Functions performed by the phonological loop, therefore, appear to correspond to the microstructural processes referred to in the W. Kintsch and van Dijk (1978, 1983) model of reading comprehension.

Although macrostructural processes resemble functions ascribed to the central executive in the model of working memory (Baddeley, 1986; 1990), Baddeley has not yet explained exactly how the central executive might be involved in reading. Apart from the study conducted by Baddeley, Logie, Nimmo-Smith, and Brereton (1985), none of his recent work on working memory in reading involves the central executive. Instead, he has concentrated on the phonological loop, possibly because its functions are more amenable to testing.

The models and developmental theories of working memory and reading presented in this chapter form the theoretical background for the studies presented in

chapter 3. In chapter 3, methods of measuring working memory are discussed in relation to measures of component reading skills and reading comprehension.

## CHAPTER 3

### WORKING MEMORY MEASUREMENT IN RELATION TO READING

#### 3.1 INTRODUCTION

There have been evolutionary changes in the measurement of working memory resulting from hypotheses and models associating it with reading. The changes have occurred largely in response to the need for improved measures for use in reading research, as many traditional measures proved unsatisfactory. Traditional and improved working memory measures are presented below.

#### 3.2 TRADITIONAL MEASURES OF WORKING MEMORY

##### 3.2.1 The Digit Span Test

Ever since Miller (1956) postulated that adults could retain seven plus or minus two chunks of information in short-term memory, the digit span test has been used as a measure of short-term/working memory capacity. It is included in most memory batteries, for example, the Wechsler Memory Scale (Wechsler & Stone, 1945), and entails the immediate sequential recall of series of random digits presented verbally. The number of digits presented on each trial increases from three to nine, and the test is discontinued when the testee fails to recall their correct sequence. Most normal adults can recall seven digits correctly.

The digit span test also forms part of children's intelligence tests, such as the Wechsler Intelligence Scale for Children - Revised (Wechsler, 1974). The number of digits recalled correctly by children

generally increases with advancing chronological age, probably as a result of development in item recognition and encoding (Huttenlocher & Burke, 1976). The relationship between performance on the digit span test and reading is discussed below.

### 3.2.2 Reading Retardation and Digit Span

Several early studies reported that retarded readers performed poorly on the digit span test compared to normal readers (Kopitz, 1975; Rugel, 1974; Spring, 1976). Ellis (1979), however, found that certain retarded readers showed no memory span deficit. Results of a study comparing groups of retarded readers with a normal digit span to groups with a poor digit span implicated the retrieval of specific verbal coding information in long-term memory (Torgesen & Houck, 1980). A more recent study by Bowers, Steffy, and Tate (1988) showed a relationship between digit span and word attack skills in normal and disabled 8- to 11-year-old readers. The word attack test involved phonological decoding of nonwords, and competent performance required the sequential retention of letter and syllable sounds for blending purposes.

Thus, there are conflicting results from studies comparing digit span and reading retardation (Perfetti & Lesgold, 1977). A possible reason for this may be that the digit span test measures several other cognitive components apart from short-term store. These are attention, sequencing, number skills, mnemonic strategies and item identification speed (Mishra, Ferguson, & King, 1985).

### 3.2.3 Other Traditional Span Tests

Talley (1986) warned against using digit span as a sole measure of short-term memory. He found that the Rey Auditory Verbal Learning Test (Rey, 1964) was a superior measure of verbal memory encoding. This test measures a testee's immediate word span and learning curve for lists of common nouns. It may, therefore, be a more specific measure of the type of phonological coding used in reading because of the linguistic nature of the test material.

Memory span tests involving words and the counting of dots were used to investigate differences in short-term memory capacity between young children and adults (Case, Kurland & Goldberg, 1982). The dot counting span test resembles a digit span test. Children aged 6 to 12 years were asked to count and remember the number of green target dots on cards, while ignoring yellow distractor dots. The cards were presented in sets of one to eight cards. The children had to remember the number of dots on each card in a set in the correct sequence. The procedure involved a counting speed and span tests during which the children were allowed to count at their own pace. Their performance was compared with that of adults on the same test. However, the adult subjects had to count in nonsense numbers, for example, "... rap slif dek ..." (p. 399). There was no significant difference between the subject groups when counting speed (operational or functional efficiency) was controlled. Case, Kurland, and Goldberg (1982) concluded that children's memory span increases as a result of operational efficiency, although mnemonic strategies, like rehearsal, may contribute. The dot counting span is considered to be a measure of nonlinguistic working memory capacity, particularly in

children (Baddeley, Logie, Nimmo-Smith, & Brereton, 1985).

As more information on the role of working memory in reading became available (Baddeley, 1984; Baddeley, Elridge, & Lewis, 1981), the interaction between specific working memory functions and reading began to be considered. Because many traditional tests of short-term or working memory capacity, such as the digit and word spans, appeared to be unreliable correlates of reading comprehension, it became necessary to find working memory measures that pertained directly to reading.

### 3.3 TOWARDS IMPROVED TESTS OF WORKING MEMORY SPAN IN RELATION TO READING

#### 3.3.1 Development of a Working Memory Span Test

Traditional measures of working memory storage capacity correlate weakly with reading comprehension (Perfetti & Lesgold, 1977), possibly because they do not involve linguistic processing (Jorm, 1983). Daneman and Carpenter (1980) suggested, therefore, that individual differences in working memory storage capacity alone could not explain differences in reading comprehension. Instead, they postulated that working memory processing functions, as well as storage capacity, were involved. This combination of processing functions and storage capacity was referred to as working memory functional capacity by Baddeley (1986, 1990) and Baddeley and Hitch (1974). In reading, like other cognitive functions, there is a trade-off between processing and storage. If text processing was poor during reading, it would reduce available storage capacity, thereby adversely affecting comprehension. Thus, there was a need to develop working memory tests for use in reading

research that tapped functional capacity.

### 3.3.2 The Reading Span Test

In response to this need, Daneman and Carpenter (1980) developed a reading span test to investigate working memory in reading comprehension in adults. This test closely approximated normal reading and, therefore, made use of linguistic processing. Furthermore, it demonstrated working memory functional capacity by reflecting the trade-off between storage (retaining the final words in each sentence) and processing functions (reading and comprehending sentences) (Daneman, 1982). Their subjects read sentences containing 13 to 16 words. The sentences were presented in sets of two to six, and the number of sentences increased progressively. After each set, they had to recall the last word in each sentence in the correct order. Other tests administered included reading comprehension and word span tests. The reading span test correlated significantly ( $r=.59$ ,  $p<.01$ ) with the measure of reading comprehension in this experiment. The word span test, which did not require text processing, did not correlate with comprehension.

A second experiment was carried out using listening as well as oral and silent reading versions of the reading span test. Again, the subjects had to read or listen to sets of sentences. They then had to judge whether the sentences were true or false to ensure that they had processed them, and to recall the last word in each sentence. As in the previous experiment, the listening ( $r=.53$ ,  $p<.01$ ) and oral ( $r=.55$ ,  $p<.01$ ) and silent ( $r=.49$ ,  $p<.01$ ) reading span results correlated significantly with reading comprehension. Daneman and Carpenter (1980) concluded that individual differences

in reading and listening comprehension could be assessed using working memory span tests that tapped both the processing and storage functions.

Many subsequent studies examining the role of working memory in a variety of reading tasks have appeared based on this approach. Masson & Miller (1983) extended the Daneman and Carpenter (1980) study. They compared a reading span test with the ability to integrate textual information and make inferences (read between the lines) from other nontextual information. Passages adapted from Walker and Meyer (1980) were used. Other tests administered included reading comprehension and letter span tests. They obtained correlations ( $r=.53$ ,  $p<.01$ ) between the reading span and reading comprehension tests similar to those obtained by Daneman and Carpenter (1980). There was also a significant correlation ( $r=.53$ ,  $p<.01$ ) between the reading span and inferential test results. It appeared, therefore, that high-level textual processing was related to the working memory span. This conclusion was further supported by the absence of a relationship between letter span, a working memory capacity test, and reading comprehension or reading span. Again, these results suggest that the reading span test measures more than working memory capacity. Its relationship to inferencing ability could indicate macrostructural processing according to the W. Kintsch and van Dijk (1978, 1983) mode of reading comprehension.

### 3.3.3 The Working Memory Span Test

Baddeley, Logie, Nimmo-Smith, and Breverton (1985) found that the complexity of the Daneman and Carpenter (1980) reading span test was both "... a strength and weakness" (p. 120). They believed that, although it



tapped various working memory functions, the complexity of this test complicated the interpretation of results. Consequently, they decided to simplify the reading span test. They developed a simplified working memory span test and used two experiments to investigate the role of working memory in fluent reading in adults. In addition to this test, they included other measures of language and reading abilities, such as letter matching (Jackson & McClelland, 1979; Posner & Mitchell, 1967), lexical decision, vocabulary and reading comprehension.

Their working memory span test was also designed to measure storage and processing functions. It comprised short sentences containing a person as a subject, a verb and an object. Half of the sentences were sensible and half, absurd. Thus, in terms of sentence structure, each proposition contained two arguments and one predicate. The subjects were asked to listen to sets comprising two, three or four sentences and this progressively increased the number of arguments to be processed and retained in working memory. There were four trials for each set. After the presentation of a sentence, the subjects had to indicate on an answer sheet whether the sentence made sense or not. They were then cued to recall either the object or subject in each sentence in the set in the correct order.

Letter matching was tested in two ways. Firstly, the subjects had to compare 80 pairs of upper or lower case letters, for example, "AA, bb, ab or AB" (p. 122) and indicate whether they were identical or different on an answer sheet. Secondly, they were given "YES" and "NO" questions and asked to produce relevant combinations of letters in response. For example, "YES" could be answered "Aa" or "Bb" and "NO", "Ab" or "Ba" (Posner & Mitchell, 1967).

The lexical decision test comprised 100 words and 100 nonwords of one syllable. The word length varied between three to six letters. Half of the nonwords were pseudohomophones and half were nonpseudohomophones. Pseudohomophones sound like real words, but are spelt incorrectly, for example, 'frute'. The nonpseudohomophonic nonwords were matched for visual similarity to a pseudohomophone by altering one letter, for example, 'fruke'. In each case, the subjects were asked to judge whether a word was real or not. Practice lists containing 16 words and 16 pseudohomophones or nonpseudohomophones were given before the test lists of 25 words and 25 pseudohomophones or nonpseudohomophones. Subjects were allowed 20 seconds to complete each test list.

Reading comprehension was measured using the Nelson-Denny Reading Test. The subjects were given 15 minutes to answer as many multiple choice questions as possible after reading a series of passages. Baddeley et al. (1985) used the Mill Hill Vocabulary Test to assess basic verbal skills, requiring the subjects to select the correct synonym for a word from six alternatives.

Significant correlations were found between reading comprehension and lexical decision ( $r=.51$ ,  $p<.001$ ), working memory ( $r=.46$ ,  $p<.001$ ), letter matching ( $r=.40$ ,  $p<.01$ ) and vocabulary ( $r=.33$ ,  $p<.01$ ) in that order. Stepwise regression analyses were carried out with reading comprehension as the dependent variable. Although the percentage of variance accounted for by the independent variables depended on the order in which they were entered into the regression equation, working memory span, lexical decision and vocabulary were all significant predictors of reading comprehension. In addition to basic verbal skills

(vocabulary) and the ability to access information from the lexicon (lexical decision), reading comprehension appeared to involve the simultaneous storage and processing of reading material in working memory. Baddeley et al. (1985) concluded that the working memory span test was a "... promising predictor of fluent reading" (p. 126).

A second experiment was conducted to assess whether reading comprehension relied on a general or language based working memory system. Reading comprehension was compared with vocabulary and working memory span, all of which involved language processing, and also with the dot counting span test (Case, Kurland, & Goldberg, 1982), a nonlinguistic measure of working memory storage and processing functions. Vocabulary and working memory span were the best predictors of reading comprehension. Although there was an correlation ( $r=.43$ ,  $p<.001$ ) between the two working memory measures, dot counting span test scores correlated weakly with reading comprehension ( $r=.29$ ,  $p<.001$ ) when compared with correlations between the latter and the working memory span test. Baddeley et al. (1985) postulated that this might indicate the presence of a specific language processor measured by the working memory span test that contributes to reading comprehension rather than a general, central executive processor measured by the dot counting test. However, these authors felt that more specific working memory measures would be needed to test this postulate. These issues were addressed by others and studies are discussed in section 3.4.

Dixon, Lefevre, and Twilley (1988) tested normal adult readers using the same reading comprehension, vocabulary, reading span and lexical decision tests as

Baddeley et al. (1985). They added inference, number-of-meanings, digit span and word-recall tests. During the inference test, the subjects read two passages and after each passage, answered six questions using "... world knowledge to make plausible inferences about the motivations and actions in the story" (Dixon, LeFevre, & Twilley, 1988, p. 467). The subjects read 50 sentences one at a time in the number-of-meanings test to decide whether a sentence had one or two meanings. The digits were presented in sets of 4 to 10 random digits by means of a tape recorder. After listening to each set, the subjects had to write down the digits in the order of presentation. A tape recorder was also used to present the monosyllabic words, which were randomly arranged in sets of 3 to 8 words in length. After listening to each set, the subjects had to write down the second last word.

The results showed significant correlations between reading comprehension and the number-of-meanings ( $r=.31$ ,  $p<.05$ ), vocabulary ( $r=.54$ ,  $p<.05$ ), lexical decision ( $r=.37$ ,  $p<.05$ ), and reading span tests ( $r=.39$ ,  $p<.05$ ). Reading span also correlated with the inferences ( $r=.28$ ,  $p<.05$ ), number-of-meanings ( $r=.27$ ,  $p<.05$ ), vocabulary ( $r=.27$ ,  $p<.05$ ), and lexical decision ( $r=.26$ ,  $p<.05$ ) tests. Digit span and word-recall correlated with reading span, but not with reading comprehension. The number-of-meanings, vocabulary and reading span tests were significant predictors of reading comprehension. These regression analyses results resembled those of Baddeley et al. (1985). However, the lexical decision test did not contribute any significant variance in the regression equation using reading comprehension as the dependent variable. Dixon, LeFevre, and Twilley (1988) concluded that reading comprehension was a multifaceted skill that

could not be measured by a single test. Furthermore, reading span related to component reading processes, such as word knowledge, speed of lexical access and text processing in addition to working memory.

In adults, therefore, working memory span tests appear to correlate with, and predict, reading comprehension. They also correlate with measures of component reading skills, such as lexical decision; language skills, such as vocabulary; and traditional measures of working memory capacity, such as the digit span.

#### 3.4 OTHER STUDIES OF WORKING MEMORY AND READING IN ADULTS

Daneman (1987) and Daneman and Tardif (1987) investigated two issues of working memory in information processing tasks in adults. The first concerned processing and storage capacity and the second, whether comprehension involves a general, central executive processor or a specific language processor (Baddeley et al., 1985). A problem with previous working memory span tests, such as the reading span test, was that they closely resembled reading. It was difficult, therefore, to assess the interaction and trade-off between storage capacity and processing, and to differentiate between a general and a specific language processor. Daneman (1987) and Daneman and Tardif (1987) devised new verbal and nonverbal tests of working memory to address these questions.

The tests were designed to evaluate the relative weights of processing and storage in language and nonverbal cognitive tasks. They included verbal, mathematical and spatial span tests during which the subjects were required to solve problems. The test

material was printed on cards and there were 45 cards in each test. They were presented one at a time in sets of two to four cards.

Each card in the verbal span test contained four words printed in a line. Two words had to be joined to form another longer word (e.g., ear fat her nest). There could be no syllable boundary between the two smaller words. In this example, "fat" and "her" could be combined without a syllable boundary to give "father". Although "ear" and "nest" could be combined to form "earnest", there is a syllable boundary between the composite words. The mathematical test cards contained three numbers. The subjects were required to combine two of the numbers without performing any mathematical operations so that the resultant number was divisible by 3 (e.g., 9 26 72 = 972). The spatial task cards contained three 3 x 3 matrices similar to those in noughts-and-crosses. Red and blue tokens were placed on some of the cells in the matrices. By examining the token placement in all three matrices on a card, the subjects had to find and point to a sequence of either three blue or three red tokens that completed a vertical, horizontal or diagonal line. After responding to the problems on all the cards in a set, the subjects had to recall their solutions in the correct order of presentation. The number of correct responses (processing) as well as sequential recall thereof (memory) were scored.

Other tests in these experiments were the Nelson-Denny Reading Test (discussed in 3.3.3), and the Vocabulary Test from the General Aptitude Battery. The Vocabulary Test consisted of 60 items, comprising four words each, two of which had either similar or opposite meanings. The subjects were required to make synonym and antonym

judgements. The reading comprehension and vocabulary scores were combined to obtain an overall measure of verbal ability. These results were compared with those obtained for processing and memory on the span tests.

Significant correlations were found between the verbal span processing ( $r=.58$ ;  $r=.55$ ;  $r=.62$ ; all  $p<.001$ ) and verbal memory ( $r=.55$ ;  $r=.56$ ;  $r=.61$ , all  $p<.001$ ) results and comprehension, vocabulary and verbal ability tests, respectively. The mathematical memory span test results showed similar but weaker correlations to those of the verbal span tests. The weaker correlations with the criterion tests, namely reading comprehension ( $r=.49$ ,  $p<.01$ ), vocabulary ( $r=.44$ ,  $p<.01$ ) and general verbal ability ( $r=.51$ ,  $p<.01$ ) were explained on the basis that the mathematical memory span test did not resemble the criterion tests as closely as the verbal span tests. The mathematical span processing test results correlated weakly with only vocabulary ( $r=.34$ ,  $p<.05$ ) and verbal abilities ( $r=.33$ ,  $p<.05$ ), and failed to relate to reading comprehension, indicating that the subjects' recall for their responses to the mathematical problems (the mathematical memory span test) appeared to tap linguistic skills to a greater extent than mathematical processing. Therefore, the mathematical tests also appeared to involve symbolic processing (i.e., the use of speech codes when subvocally rehearsing the number strings in order to recall them) and storage, although in their case, the symbols were numbers instead of words. The spatial span tests involved no symbolic processing or storage and showed no relationship to the criterion, verbal or mathematical tests. Thus, the mode of processing (verbal/symbolic versus spatial) appeared to be the critical factor in predicting reading comprehension. These findings supported the hypothesis concerning

separate language and spatial processors (Daneman, 1987; Daneman & Tardif, 1987).

To assess whether there was a trade-off between storage demands and processing, subjects performed "memory-free" versions of the verbal, mathematical and spatial tests. However, Daneman (1987) and Daneman and Tardif (1987) conceded that there would be some need for temporary storage during the processing tasks, although the specific memory demands of recall following processing had been removed. The comparison of these "memory-free" processing tests with reading comprehension, vocabulary and verbal ability produced similar correlations to those when the memory component was included. The findings were interpreted as meaning that the functional capacity of the processor depended on operational efficiency rather than storage capacity.

Baddeloy's model of working memory (1986, 1990) would suggest that the verbal and mathematical span tests depended on the phonological loop and central executive, and the spatial span task, the visuo-spatial sketch pad and central executive. As their results seemed to emphasize the importance of processing over storage, Daneman (1987) and Daneman and Tardif (1987) raised the question of whether the slave systems could incorporate a symbolic and a spatial processor capable of performing the processing tasks usually assigned to the central executive. This would render the construct of the central executive obsolete, and necessitate the reconceptualization of the working memory model.

Following the Daneman (1987) and Daneman and Tardif (1987) publications, Turner and Engle (1989) devised and tested complex verbal and numerical span measures on undergraduate university students. Results on their



measures were compared with reading comprehension and with traditional digit and word span test scores. The complex verbal span test consisted of sets of sentences resembling those of Daneman (1980). They modified the Daneman procedure in that one trial required the subjects to recall the last word of each sentence (Sentence Word), and the next, the digit that followed each sentence (Sentence Digit). After each sentence, the subjects had to verify them so as to ensure sentence processing and comprehension. The numerical span involved verifying sets of arithmetic operations, (for example,  $(9/3) - 2 = 1$ ), some of which were followed by a word (Operations Word), and some, by a digit (Operations Digit). In addition to these complex measures, they also included simple, traditional digit and word span tests and the Nelson-Denny Reading Test.

The results showed that all the complex span scores, namely Sentence Word ( $r=.37$ ,  $p<.001$ ), Sentence Digit ( $r=.20$ ,  $p<.01$ ), Operations Word ( $r=.40$ ,  $p<.001$ ) and Operations Digit ( $r=.24$ ,  $p<.01$ ), correlated with reading comprehension, the highest correlations being obtained from the Sentence and Operations Word span tests. The Sentence and Operations Digit span tests were less significantly correlated with reading comprehension. In this, their results resembled those of Daneman (1987) and Daneman and Tardif (1987). Although they conceded that these tasks might all depend on verbal/symbolic processing, they concluded that measures of working memory functional capacity did not have to be task dependent, which contradicts the Daneman (1987) and Daneman and Tardif (1987) conclusions. Traditional word and digit span did not correlate with reading comprehension. In the latter, Turner and Engle (1989) argued that the tasks relied on rehearsal and chunking rather than processing. It

followed, therefore, that they should not be related to reading comprehension, which involved processing as the complex span tests did.

In a follow-up study, La Pointe and Engle (1990) again compared simple and complex word spans in relation to comprehension in undergraduate university students. Their simple word span tasks comprised sets of two to eight short or long words that were matched for frequency. The words were presented one at a time by computer. The subjects were asked to read all the words in a set and then recall them in any order. This was followed by a complex numerical task requiring the verification of sets of arithmetic statements (for example, [does  $(8 \times 1) + 8 = 16?$ ]), each of which were succeeded by a word to be remembered. Other tests included a reading comprehension test and a reading span test comprising sets of sentences to be read aloud, each followed by a word to be remembered.

The comprehension and complex reading span results were compared with those of the word span and complex numerical task. La Pointe and Engle (1990) reported that the simple word span test predicted comprehension for both short and long words, although they were unable to say why this was so, as previous studies had not obtained this result. Daneman and Carpenter (1980) and Turner and Engle (1989), for example, had showed that simple word span tests did not predict reading comprehension, probably because they did not involve the same linguistic/memory processes and strategies. Both the complex numerical ( $r=.48$ ,  $p<.01$ ) and reading span tests ( $r=.54$ ,  $p<.01$ ), however, which involved symbolic processing, correlated with reading comprehension as they had done in the Turner and Engle (1989) study.

In summary, the following are relevant with regard to the role that working memory may play in fluent reading in children. Firstly, the studies quoted all used mature adult readers and, therefore, the results may not necessarily be generalized to children. Secondly, specific skills vital for reading development, such as phonological coding, were not assessed. Information on the role of working memory in phonological coding would be of particular interest in the case of younger school-going children, who still use phonological strategies to a large extent when reading. Studies addressing these issues are reported in section 3.5.

### 3.5 WORKING MEMORY MEASURES AND READING IN CHILDREN

#### 3.5.1 Working Memory and Reading Comprehension

Some recent studies of working memory in reading comprehension in children have investigated the issue of trade-off between processing and storage based on the the Kintsch and van Dijk (1978, 1983) model. Younger children and children with reading disabilities would be expected to devote more time to decoding words and microstructural processing than to macroprocessing. Inefficiencies or difficulties in decoding and microprocessing would result in limited resources for storage and for attention to higher-level processing, such as comprehension (Hess & Radtke, 1981).

Torgesen, Rashotte, and Greenstein (1988) compared normal children with two learning disabled groups in retaining sequences of verbal material. The one learning disabled group had a normal short-term memory span, and the other, a below average memory span. The learning disabled children's reading and/or mathematical achievement scores at school were at least 18 months below chronological age expectations. Results

on a working memory span test, similar to that used by Baddeley et al. (1985), a listening comprehension test requiring gist recall for unfamiliar passages, and a block manipulation task, requiring the ability to follow a sequence of instructions, were compared with reading comprehension scores.

There were no significant differences between the two learning disabled groups on the listening and reading comprehension tests. However, the learning disabled children with poor short-term memory performed poorly in recalling specific words and word order in the working memory span test and very poorly on the block task. Inadequate rehearsal and chunking strategies, relating to inefficient phonological loop functions, appeared to account for their poor performance on the working memory span test. Competent performance on the block manipulation task required the retention and organization of large chunks of information.

Torgesen, Rashotte, and Greenstein (1988) interpreted the results of the learning disabled children with poor short-term memory as suggesting difficulty in the use of "... phonological codes to store verbal information in working memory" (p. 486). However, they may also relate to the phonological short-term store in the phonological loop. This store acts as a "mnemonic window" (Baddeley, Vallar, & Wilson, 1987) in comprehension tasks, and the number of chunks for storage in order to understand discourse depends on the syntactical complexity of the discourse. It was suggested that these children have inadequate rehearsal and chunking strategies and, consequently, may have limited information storage capabilities in the window at one time. These findings imply difficulties in following syntactically complex instructions in class

as well as in understanding complex text because processing capabilities were limited by the amount of available storage. Thus the trade-off between storage and processing appears to be more marked in children than in adults.

Yuill, Oakhill, and Parkin (1989) matched children of 7 to 8 years who performed well and poorly on tests of reading comprehension for letter recognition and digit span. They first read sets of lists of numbers and were then asked to recall the last number in the list in the correct order for each set. The poor comprehenders scored significantly worse on the longer number lists compared with the good comprehenders. They were then asked to detect anomalies in sentences. The anomalies occurred next to, and two sentences away from, and either before, or after, the resolution, which imposed varied loads on working memory. There was a generalized deficit in storing information from distant sentences during a concurrent language processing task amongst the poor comprehenders, suggesting limitations in working memory functional capacity in these children.

Siegel and Ryan (1989) compared reading- and arithmetic-disabled children and attention deficit children with normal controls on reading and arithmetic subtests of the Wide Range Achievement Test, an auditory working memory listening span test, resembling that of Daneman and Carpenter (1980), and the dot counting span test (Case, Kurland, & Goldberg, 1982). The ages of the subjects ranged from 7 to 13 years. The younger normal controls ( $x=3.13$ ,  $sd=1.5$ ) and the reading-disabled children of all ages (7 - 8 years:  $x=1.84$ ,  $sd=1.1$ ; 9 - 10 years:  $x=2.18$ ,  $sd=1.4$ ; 11 - 13 years:  $x=4.29$ ,  $sd=1.4$ ) had significantly smaller listening spans than the older normal controls ( $x=5.91$ ,

sd=1.9). Both the arithmetic- and reading-disabled subjects performed more poorly than the normal controls on the dot counting span test ( $F[2,114]=27.09, p<.001$ ).

These results were interpreted as follows. The reading- but not the arithmetic-disabled children had difficulty with the listening span test. This test involved the processing of words and grammatical structure in addition to memory. However, all the disabled children had difficulty with the dot counting span test, which is thought to be a more generalized test of working memory processing and storage. With the exception of the youngest subjects' performance on the listening span test, the attention deficit group did not perform significantly differently to the normal controls. Siegel and Ryan (1989) concluded that working memory deficits may be related to specific learning disabilities. Different patterns of deficits (i.e., linguistic and numerical) may be observed in different types of learning disabilities.

All of the above studies suggest that learning disabled children struggle with tasks requiring simultaneous storage and processing. Again, this appears to be due to a limited phonological short-term store, which impedes processing at both micro- and macrostructural levels.

### 3.5.2 Working Memory and Component Reading Skills

Baddeley and Hitch (1974) and Baddeley (1986, 1990) suggest that phonological coding is a function of working memory and this has received particular attention in studies of reading retardation. Cataldo and Ellis (1988) state, "In the early formulative stages of reading implicit phonemic awareness and

reading act reciprocally to build skill in each other" (p. 86). Phonological coding deficits, therefore, cause concern as they relate significantly to difficulties in acquiring early reading skills (Vellutino & Scanlon, 1987). Phonological short-term store is another working memory function that appears to contribute to developmental and individual differences in reading performance (Gathercole & Baddeley, 1990).

Siegel and Ryan (1988) compared normal controls with reading disabled children on a number of language, reading and short-term memory tests. The subjects were aged from 7 to 14 years. The tests included the reading and spelling of nonwords, the reading of regular and irregular words and a test of reading comprehension, the Gilmore Oral Reading Test. The short-term memory test involved recalling printed sequences of letters, either rhyming (C E G T B) or nonrhyming (H L K P M) after 3- and 6-second exposures.

Developmental trends were present on all the tests. The reading disabled subjects, however, performed more poorly on the tests requiring letter-sound conversion knowledge, such as reading regular words and nonwords. However, this group's irregular word-reading was superior to regular word-reading, suggesting that they compensated for their difficulties by using of whole-word strategies via the lexical reading route. The reading disabled group performed more poorly than normal controls in the short-term memory test, and in recalling rhyming letters in particular. This group's slow and ineffective access of phonological codes had led to the inadequate development of phonological reading skills and to poor reading of unfamiliar words. Reading comprehension correlated significantly with the accuracy of word recognition ( $r=.56$ ,  $p<.001$ ) and the

ability to read nonwords ( $r=.62$ ,  $p<.001$ ) in the group as a whole. Therefore, poor phonological skills in the reading disabled group may also have impeded comprehension. In this study, however, it appears that children with only phonological reading difficulties were tested. Other forms of reading disorder, such as the inability to read lexically, were not considered.

Gathercole and Baddeley (1990) tested the role of phonological short-term store in language skills and disabilities. Their experiments compared language disabled children with two normal control groups, matched for verbal and nonverbal abilities respectively, on various phonological working memory tests. The tests included nonword repetition (one to four syllables in length), serial recall (including phonologically similar and dissimilar words), auditory perception of, and discrimination between, phonologically similar and dissimilar words, and rate of articulation. The language disabled group showed generalized phonological memory deficits, apparently related to either auditory perceptual or articulatory problems and not to phonological coding or rehearsal difficulties. Gathercole and Baddeley (1990) suggested that the memory deficits were related to developmental language disorders. However, the group of language disabled subjects consisted of only six children. An unrepresentative sample such as this may account for the absence of significant differences between the subject and control groups in phonological coding and rehearsal.

In general, strong developmental trends are present in phonological coding and memory in children. These skills are important in language and reading acquisition. It seems likely that such developmental



trends will be evident in the present study.

### 3.6 PROBLEMS RELATING TO SUBJECT SELECTION IN READING RETARDATION RESEARCH

Many studies have examined the potential relationship between working memory and reading abilities in beginner and mature readers, and normal and reading disabled children (Brady, 1986; Jorm, 1983; Mann, 1984; Perfetti & Lesgold, 1977). However, results are conflicting in studies using children with reading disabilities. This may be due to the choice of subjects and controls.

Disabled readers and normal controls are often matched for chronological and/or reading ages (Ackerman, 1984; Jorm, 1983; Oakhill & Yuill, 1986; Yuill, Oakhill, & Parkin, 1989). Some subject groups comprised children of a specific age while in others, ages ranged over a few years. In the latter, developmental differences within, and between, groups in reading and memory skills may have invalidated results. Vellutino and Scanlon (1989) have warned against matching poor and normal readers for chronological age and/or reading level. Studies using this methodology yield controversial results because of the variety of interpretations made, particularly with regard to causal relations.

Many researchers have treated reading or learning disabled groups as though their disabilities were homogeneous, and this is inaccurate. Reading disabled children can be classified into three groups according criteria based on comprehension and coding (Aaron, 1991). Specific reading disabled children show adequate comprehension but poor coding skills, and nonspecific

reading disabled children, poor comprehension but adequate coding skills. Children with global cognitive deficits are poor at both comprehension and coding. Ellis and Large (1987) also advocated separating specific from generalized reading disabilities.

In addition to these criteria, reading disabilities (dyslexias) can be classified according to specific weaknesses and reading errors (Patterson, 1981). These include the inability to read irregular words (surface dyslexia) and unfamiliar words and nonwords (deep and phonological dyslexias), and semantic (deep dyslexia) and visual and derivational errors (deep and phonological dyslexias).

The diversity of reading disorders means that reading disabled children are not satisfactory subjects for developmental reading research. This discussion highlights the necessity for using normal readers as subjects.

### 3.7 CONCLUSIONS

The trade-off between storage and processing in working memory during cognitive tasks appears to be more pronounced in children than in adults. These functions are accredited to either a general, central executive or a specific language processor. The postulation of separate language and spatial processors in working memory (Baddeley et al., 1985; Daneman, 1987; Daneman & Tardif, 1987) is exciting. The phonological loop may, therefore, be a slave system to a verbal/symbolic processor. Another possibility is that the slave systems themselves may be processors. However, the Daneman (1987) and Daneman and Tardif (1987) research in this area was carried out in adults and needs to be replicated in children.

These studies give rise to the possibility that working memory plays an important role in fluent reading in children. However, the available research on reading and working memory development has compared groups of normal and reading disabled subjects. Thus, there is little information available about normal developmental changes in working memory and their implications for fluent reading. Working memory functional capacity appears to change with age, and consequently, there may be developmental differences in its relationship with component reading skills and reading comprehension in normal children, let alone disabled readers. Such changes are potentially important in the understanding of reading retardation. This emphasizes the need for a developmental study of the role of working memory in reading in normal children of various ages.

## CHAPTER 4 AIM AND HYPOTHESES

### 4.1 AIM

The absence of developmental studies of working memory and reading in normal children provides the rationale for the present investigation. Its aim is to investigate the role of working memory in component reading skills and reading comprehension in such children from a developmental perspective. In order to provide a link between the working memory and reading comprehension constructs, the Baddeley (1986, 1990) model of working memory and models of reading development (e.g., Coltheart & Harris, 1986) and reading comprehension (e.g., Kintsch, W. & van Dijk, 1978, van Dijk & Kintsch, W., 1983) formed the necessary theoretical framework. The Baddeley et al. (1985) study was replicated with some modifications to accommodate factors relevant to reading development in children.

The subjects were in standards 1, 3 and 5 and were all normal readers selected according to strict criteria. These standards were chosen specifically because the youngest children should have had sufficient educational experience to cope with group testing procedures. Furthermore, it was postulated that the standard (Std) 1, 3 and 5 subjects should be at different stages of reading development and, therefore, their results should reflect developmental trends in nonlexical and lexical reading strategies and comprehension. The relative operational efficiencies of

working memory of these groups should also reflect developmental trends in functional capacity. This might relate to performance differences between the groups in reading tasks.

Baddeley et al. (1985) used tests of reading comprehension, reading speed, vocabulary, complex working memory span, letter code and lexical access. The present investigation used this battery without letter code and reading speed tests and included tests of listening comprehension, traditional working memory span and phonological coding tests. The reasons behind the inclusion or omission of these tests were as follows:

- i. Listening comprehension should show developmental differences in correlation patterns with reading comprehension (Durrell & Hayes, 1970). Listening comprehension and reading comprehension should show a lag in the younger children.
- ii. Traditional working memory span tests should be correlated with phonological coding/word attack skills (Bowers, Steffy, & Tate, 1988; Talley, 1986).
- iii. The degree of correlation between phonological coding tests and reading comprehension should indicate the extent to which the nonlexical reading route contributes to comprehension.
- iv. The letter code test was omitted on the basis of being both irrelevant to the aim of the study and superfluous in the light of the inclusion of lexical decision tests. The latter tests assess lexical access and orthographic knowledge, and correlate highly with reading comprehension in adults according

to Jackson and McClelland (1979). Lexical decision tests should also reflect the use of lexical reading strategies in children.

v. As the children were tested in groups in their classrooms, it was not possible to assess each child's reading speed individually. However, the standardized reading comprehension tests had to be completed within a specified time. Therefore, slow readers lost marks for not completing the test.

A correlational approach was used to identify the component reading and working memory variables that contribute towards the development of fluent reading in children. The reading and working memory variables, showing the most significant correlation with reading comprehension, were entered into regression equations to assess their relative contributions to the prediction of fluent reading. Further regression analyses were performed to examine the relationship between working memory and component reading variables. The pattern of correlations was assessed from a developmental perspective for specific patterns at each educational level. Although the correlation and regression results would not imply causation, they might indicate important relationships between working memory and reading skills.

#### 4.2 HYPOTHESES

i. There will be a significant relationship between working memory as measured by complex and traditional working memory span tests and reading comprehension.

ii. There will be significant relationships between all tests of working memory involving symbolic coding and tests of component reading skills.

iii. There will be a significant relationship between listening comprehension, vocabulary and reading comprehension.

iv. There will be a significant relationship between the cognitive components of the reading process and reading comprehension.

v. There will be a significant relationship between working memory, listening comprehension and vocabulary.

vi. There will be a significant relationship between traditional tests of working memory and the complex memory span tests.

vii. There will be developmental differences in working memory and reading.

## CHAPTER 5

### PILOT STUDY: METHOD, RESULTS AND DISCUSSION

#### 5.1 INTRODUCTION

The pilot study was aimed at determining whether the materials and test procedures were appropriate for use with the subjects. As the subjects varied in age and level of education, differences in cognitive development might result in floor or ceiling effects in certain tests. These tests might then require modification.

#### 5.2 METHOD

##### 5.2.1 Research Design

A nonexperimental research design was used in this pilot study to investigate the relationship between the independent variables, working memory skills and components of the reading process and language skills and the dependent variable, reading comprehension. The dependent variable was derived from a standardized reading comprehension test. The independent language variables came from listening comprehension and vocabulary tests, and component reading skill variables from tests of phonological coding and orthographic knowledge. The independent variables relating to working memory came from reading, listening, digit, word, and dot counting span tests. Normal Std 1, 3 and 5 readers were selected for this study.

As often happens with human science research, this study did not lend itself to an experimental design



(Kerlinger, 1986). Thus, a nonexperimental research design was used in the pilot and main studies because the independent variables were characteristics inherent in the subjects and could not be controlled or manipulated. Instead, they were measured in terms of the subjects' performances on a variety of memory, language and reading tasks. The subjects could not be randomly assigned to treatment groups, and were grouped according to their educational level. Control of extraneous variables was exercised as follows:

- i. The subjects were selected according to strict criteria.
- ii. Some standardized measuring techniques were employed.
- iii. The instructions and administration procedures for each nonstandardized test was identical for all subjects.
- iv. Testroom conditions were controlled as far as possible.

This design permitted correlational inferences between the dependent and independent variables to be made. Causality was, however, not necessarily implied.

#### 5.2.2 Subjects

Altogether 270 English-speaking Std 1, 3, and 5 pupils were tested in Transvaal Education Department Primary Schools. After testing, 132 normal subjects were selected on the basis of an average reading comprehension score defined as falling within the fourth to the sixth stanine on standardized reading

comprehension tests that were appropriate for each standard. The subjects also complied with the following criteria:

- a) No significant medical or psychiatric history.
- b) No evidence of a specific learning disability.
- c) A normal scholastic achievement record.
- d) Classification within the "average" range on the New South African Group Test (NSAGT) or equivalent intelligence test.
- e) Socio-economic status to be "middle-class".

The subjects were divided into three groups according to standard of education as shown in Table 1. There were 40 Std 1, 54 Std 3 and 38 Std 5 pupils. The mean ages were 9.20, 11.05 and 13.16 years respectively.

TABLE 1  
Subjects included in the Pilot Study.

| STANDARD | N  | MEAN AGE |
|----------|----|----------|
| 1        | 40 | 9.20     |
| 3        | 54 | 11.05    |
| 5        | 38 | 13.16    |

### 5.2.3 Materials

The test materials were selected or compiled to assess firstly, various skills involved in fluent reading, and secondly, verbal and nonverbal working memory. All tests were in pencil and paper format.

(a) Word tests

(i) Component Reading Skills

The words used in these tests were selected in consultation with experienced Std 1 teachers from the prescribed Std 1 basal reading series. They were, therefore, familiar to Std 1 pupils, and their frequencies were obtained from Kucera and Francis (1967). They were matched for length, number of syllables, part of speech, and frequency. Words and nonwords that resembled Afrikaans words were not used so as to prevent confusion. The following tests were included:

SILENT TESTS OF PHONOLOGY:

Rhyming and nonrhyming, regular and irregular, word-pairs were compiled based on Coltheart (1981) to assess the children's ability to access phonological codes when reading regular and irregular words and nonwords. Regular words follow the letter-sound correspondence rules of English orthography, while irregular words do not. Nonwords, consisting of strings of letters following the letter-sound conversion rules of English orthography, were constructed to match the real words. These could, therefore, be read by applying the rules.

One practice and two test lists of regular and irregular word-pairs and nonword-pairs were compiled (see appendices A to E). Each practice list contained 6, and each test list 20, randomly arranged homophonous (sounding the same) and nonhomophonous (having different sounds) graphically similar control pairs. Examples of these are SAIL - SALE, SAIL - SALT (regular words); HALL - HAUL, HALL - HILL (irregular words); and AFE - AIF, AIF - AUF (nonwords).

#### LEXICAL DECISION TESTS:

A practice list of 16 words, and four test lists of 25 words each were constructed to investigate the subjects' ability to distinguish between words and nonwords, which were pseudohomophones and nonpseudohomophones (see appendices F to H). Pseudohomophones are nonwords that sound like English words. Nonpseudohomophones are nonwords that do not sound like English words and are derived from real words by changing a single letter. None of the words was a homophone of any English words, and this was ascertained by checking against lists of homophones in Kreuze (1987). The practice list included eight words and eight nonwords. Of these nonwords, four were pseudohomophones and four, nonpseudohomophones. Two test lists contained 25 words and 25 pseudohomophones in a random order, for example COW and KOW; BOAT and BOTE. The other two test lists contained 25 words and 25 nonpseudohomophones in a random order, for example: SUM and WUM; BOX and TOX.

#### VOCABULARY TEST:

In this study, tests of vocabulary appropriate to each level of education were administered to assess the children's ability to access semantic representations of printed words from the lexicon. The HSRC Std 1 (Clark & Kritzing, 1973), Std 3 (Clark & Kritzing, 1973) and Std 5 (Kritzing, 1979) English First Language Vocabulary Tests (Form A) were given. These were standardized on English-speaking South African primary school pupils. Examples of these tests are given in Appendices I to K. The tests consist of 20, 23 and 31 questions respectively and involve synonym judgements with multiple-choice answers. Each test is preceded by three practice examples.

(ii) Working Memory Span Tests

WORD SPAN TEST:

A single presentation of the Rey Auditory Verbal Learning Test List A was used (Rey, 1964). This list comprises 15 common, high frequency nouns. Five words from List B were used as a practice list (see Appendix L).

(b) Sentence and Paragraph Tests

(i) Reading and Language Tests

READING COMPREHENSION TEST:

It was crucial to select reading comprehension tests that were suited to the children's cultural background and levels of education. As with the Baddeley et al. (1985) study, reading comprehension was the outcome variable, and was, therefore, compared with the results of all the other language and memory tests used in this study. The HSRC Std 1 (Clark & Kritzinger, 1973), Std 3 (Clark & Kritzinger, 1973) and Std 5 (Kritzinger, 1979) English First Language Reading Comprehension Tests (Form A) were given. These were also standardized on English-speaking primary school pupils. Each test comprises short passages followed by multiple-choice comprehension questions, and is preceded by a practice passage and questions. Examples of these tests are in Appendices M to O.

LISTENING COMPREHENSION TEST:

Passages from the HSRC Std 1 (Clark & Kritzinger, 1973), Std 3 (Clark & Kritzinger, 1973) and Std 5 (Kritzinger, 1979) English First Language Reading Comprehension paragraphs (Form B) were read to the children. The multiple-choice comprehension questions for each passage appeared on answer sheets. Again, a

practice passage with questions preceded the test. Examples of these tests are in Appendices P to R.

#### (ii) Complex Working Memory Tests

##### WORKING MEMORY READING SPAN TEST:

Practice and test sentences were compiled and printed on transparencies. Each sentence contained a subject (either an animal or a person), a verb and an object and was based on the Baddeley et al. (1985) adaptation of the technique used by Daneman and Carpenter (1980). The subjects were printed in red, the objects in green, and the articles and verbs in black. Half the sentences were meaningful and half meaningless. For example: "THE MAN ATE THE APPLE" and "THE GIRL SANG THE WATER". The number of sentences in a series increased from two to four (see Appendix S).

##### WORKING MEMORY LISTENING SPAN TEST:

Practice and test sentences similar to those presented during the reading span test were constructed. The number of sentences in a series also increased from two to four (see Appendix V).

#### (c) Other Memory Tests

Traditional working memory tests involving verbal, numerical and nonverbal/spatial processing and storage were administered.

##### DIGIT SPAN TEST:

The Digit Span subtest of the Wechsler Intelligence Scale for Children - Revised (WISC-R) was given (Wechsler, 1974). This consists of series of digits to be recalled in the correct serial order. These series are between three to eight digits long (see Appendix

Y).

DOT COUNTING SPAN TEST (Case, Kurland, & Goldberg, 1982):

Fifteen sets of white cards with randomly arranged green (target) and yellow (filler) dots were used. There were from one to five cards in a set and there were three practice and test trials in each set. The cards measured 15 by 13cm, and the dots, 1,3cm in diameter. The yellow dots served to disrupt patterns made by the green, target dots (see Appendices Zi and Zii).

#### 5.2.4 Procedure

The children were grouped according to standard of education and were tested at school in their classrooms. The seating was arranged to minimize the possibility of copying from one another. The study was introduced before testing to explain its purpose. The children were told that the test results would reveal what processes took place inside their heads during reading and whether they could remember what they read and heard. Each child was to try his/her best during testing, but no one was expected to complete all the tests. They were assured that the tests were not for scholastic evaluation. Spelling errors would not be penalized.

The tests were administered in several sessions of about an hour each and were presented in a random order, with the exception of the working memory listening span test, to minimize practice effects. The listening span test was always scheduled after the working memory reading span test had been given to facilitate understanding of its instructions. The

children were allowed a short break between tests if more than one was administered in a session. The children cleared their desks prior to testing except for a pencil and an eraser. At the beginning of each session, test materials, such as answer booklets and sheets, were distributed. The children wrote their names, ages and classes on the front page of the answer booklets or sheets, and were required not to turn to the test pages until told to do so. All tests were preceded by practice items to familiarize the children with procedures. Their performance on practice items was checked to ensure that each child in the group understood what was required before testing commenced. The tests were administered as follows:

#### READING COMPREHENSION TEST:

The instructions were read to the children as given in the administration manuals (Kritzinger, 1979, 1986). Thereafter, they were assisted with the practice items, which involved reading the practice passages and questions in the test booklets and selecting the appropriate answers from four (Std 1) or five (Std 3 and 5) alternatives A, B, C, D/E. They indicated their choice by marking the letter adjacent to the relevant question number on the answer sheets. Their answers to the practice items were then checked and they were allowed to correct mistakes. The tests were administered once everyone understood what was required of him/her, and were performed within prescribed time limits. These varied according to standard of education. Std 1 pupils were allowed 15 minutes, Std 3 pupils, 18 minutes, and Std 5 pupils, 30 minutes for test completion. The children were instructed when to start and finish working on the tests. The tests were similar to the practice items in that they involved reading the test passages and questions and marking the



answer of their choice on the answer sheets.

#### LISTENING COMPREHENSION TEST:

The children were instructed to listen carefully during the auditory presentation of the practice and then test passages. After each presentation, they read the relevant questions on the answer sheets and marked the answer of their choice from four (Std 1) or five (Std 3 and 5) alternatives (A to D/E).

#### VOCABULARY TEST:

The instructions were read to the children as prescribed in the administration manuals (Kritzinger, 1979, 1985). They had to choose the most correct of four or five alternative meanings (A to D/E) for practice and test words and indicate their choice by marking the appropriate letter adjacent to the item number on the answer sheets. These tests were also performed within prescribed time limits. Std 1 pupils were allowed 11 minutes, Std 3 pupils, 9 minutes, and Std 5 pupils, 15 minutes for test completion.

#### SILENT TESTS OF PHONOLOGY:

The regular, irregular or nonword practice lists preceded the appropriate test list, and all the children in a group began working on them at the same time. After explanations and examples of what they had to do, the children read the practice and then the word-pairs silently and decided whether they rhymed or not. They placed a tick in the "YES" column next to the respective word-pair on the answer sheet if they rhymed, and in the "NO" column if they did not. Each child was allowed to complete all the words on each list.

#### LEXICAL DECISION TESTS:

As with the silent test of phonology, the children completed the appropriate practice lists before embarking on the word/nonpseudohomophone or word/pseudohomophone test lists. They were instructed to read the items one at a time and to decide whether they were real words or not. Responses were indicated by placing ticks in the appropriate "REAL WORD" or "NOT A WORD" columns. There was a time limit of 20 seconds for each test list irrespective of standard of education. The children completed as many items as possible in the time available, drawing a line underneath the last completed item. Thereafter, they completed the remaining items in that list. This was done to estimate an individual's speed of lexical access as well as the total nonpseudohomophone (visually similar) and pseudohomophone (phonologically similar) errors they made.

#### WORKING MEMORY READING SPAN TEST:

This test comprised series of two, three and four sentences. Each series was presented four times, amounting to 36 unique sentences. They were projected individually onto a screen using an overhead projector for 5 seconds. Immediately after reading each sentence, the children had to judge whether it made sense or not and to respond by placing a tick in either the "SENSE" or "NONSENSE" columns next to the appropriate sentence number. After a series had been presented, the children were required to recall and record the cue words (see below) from each sentence in the order presented.

Baddeley et al. (1985) used "subject" and "object" cues that were randomly assigned to a series to ensure unpredictability. This obviated selective retention of cues and guessing. To prevent the younger children in

this study confusing subjects and objects, the subject words were always printed in red ink and the object words, in green. Cueing was, thus, either "the subject or RED word" or "the object or GREEN word". If a child could not recall a cue word, this was indicated by a short line in the respective serial position in the answer booklet. This ensured that he/she was given credit for those cue words recalled in the correct serial order even if some were forgotten.

#### WORKING MEMORY LISTENING SPAN TEST:

The procedure was similar to that of the reading span test, but instead of reading the sentences, the children listened while the sentences were read. The cues "subject or first word" and "object or last word" were used.

#### WORD SPAN TEST:

The children recalled and re ordered as many words as possible from a series presented at a rate of one word per second. The practice series contained 5 words and the test series, 15. The order of recall was not considered.

#### DIGIT SPAN TEST:

Standardised instructions were given (WISC-R Manual, Wechsler, 1974), and digit presented at a rate of one per second. The children recorded as many as possible in the correct sequence after each presentation.

#### DOT COUNTING SPAN TEST:

The cards were grouped in sets of one to five. The one- and two-card sets were the practice items. The cards were shown one at a time and the children counted and remembered the number of green target dots on each card in a set. There were three trials for each set size. At

the end of each trial, the children recorded the number of green dots on each card in the correct sequence. The children drew a short line if unable to recall a number in a sequence.

### 5.3 RESULTS

Standardized tests were scored according to instructions in the manuals. Scoring stencils were made and used for marking many of the other tests. Scoring methods for each test are discussed below.

The raw data were entered onto spread sheets using the Lotus 123 computer program. These data were then sorted according to the reading comprehension stanines and the subjects selected on the basis of an average score, that is, falling within the fourth to the sixth stanines. Means and standard deviations were calculated separately for the three groups on all the reading/language and working memory variables, and these are shown in Table 2 and Table 3 respectively. No further statistical analyses were performed as certain anomalies had been detected in some of the test materials and procedures.

#### READING AND LISTENING COMPREHENSION AND VOCABULARY:

The Std 1 answer booklets were scored by hand, whereas the Std 3 and 5 answer sheets were scored using the appropriate scoring masks. A raw score was obtained from the total number of correct choices made by each child. This was converted to a stanine and a percentile using the procedure and norm tables given in the manuals (Kritzinger, 1979, 1985). The percentile for reading comprehension represented the dependent variable for analyses, whereas percentiles for listening comprehension and vocabulary were independent

variables.

TABLE 2

Mean Scores and Standard deviations obtained by Pilot Subjects on Reading and Language Tests

| STD |      | READING COMPREHENSION | VOCABULARY | LISTENING COMPREHENSION | SILENT TESTS OF PHONOLOGY |                 |          | LEXICAL DECISION TESTS |              |              |              |
|-----|------|-----------------------|------------|-------------------------|---------------------------|-----------------|----------|------------------------|--------------|--------------|--------------|
|     |      |                       |            |                         | REGULAR WORDS             | IRREGULAR WORDS | NONWORDS | NONPSEUDO-WORDS        | PSEUDO-WORDS | PSEUDO-WORDS | PSEUDO-WORDS |
| 1   | MEAN | 56.43                 | 55.59      | 72.97                   | 31.73                     | 32.56           | 36.38    | 19.26                  | 5.29         | 26.47        | 3.42         |
|     | SD   | 14.39                 | 21.36      | 15.06                   | 3.87                      | 3.72            | 5.62     | 8.21                   | 4.13         | 7.18         | 4.85         |
| 3   | MEAN | 50.44                 | 44.63      | 59.83                   | 30.23                     | 29.86           | 24.54    | 40.04                  | 3.80         | 37.61        | 4.78         |
|     | SD   | 10.42                 | 25.34      | 20.00                   | 5.50                      | 4.77            | 5.15     | 6.71                   | 2.64         | 6.47         | 4.32         |
| 5   | MEAN | 43.61                 | 56.66      | 33.13                   | 37.89                     | 36.48           | 35.32    | 42.00                  | 1.37         | 37.48        | 1.34         |
|     | SD   | 14.52                 | 26.80      | 21.03                   | 2.31                      | 2.90            | 3.16     | 0.26                   | 1.51         | 12.17        | 2.89         |

The mean percentiles achieved for reading comprehension by the Std 1, 3 and 5 subjects were 56.43, 50.44 and 43.61 respectively. These percentiles are equivalent to a stanine of 5 (range 40 to 59), which is classified as average. A similar pattern can be seen in the mean percentiles achieved for vocabulary. However, the mean percentiles for listening comprehension showed considerable variance between the standards. The mean percentile obtained by Std 1 subjects (72.97) fell within the 6th stanine (60 to 70) and that of the Std 3 subjects (59.83) within the 5th stanine. The mean percentile obtained by the Std 5 subjects (33.13) was lower than the others and fell within the 4th stanine (23 to 39). All these stanines are classified as average.

SILENT TESTS OF PHONOLOGY:

The scores represented the total number of correct responses to the rhyming and nonrhyming word-pairs out of 40 in each category (i.e., regular, irregular and nonword word lists). The phonology test results in Table 2 represent mean raw scores. As the same tests were used for all subjects, it was hypothesized that

the results should show developmental trends according to standard of education. However, differences between the Std 1 and 5 subjects were not as large as expected. These mean raw scores were 33.73 and 37.59 for regular words, 32.56 and 36.68 for irregular words and 30.38 and 35.32 for nonwords, respectively. It was then decided to impose a 20-second time limit for the Std 3 subjects after it had been checked for ceiling effects with some of the better Std 5 readers. The Std 3 means were 30.23 for regular words, 29.96 for irregular words and 24.54 for nonwords.

#### LEXICAL DECISION TESTS:

The scores for accurate discrimination between word and nonpseudohomophones and words and pseudohomophones represented the number of items completed correctly within the time limit. The maximum possible scores were 50 in both categories. Nonhomophonous and pseudohomophonous error scores were obtained from the total number of respective errors made. The lexical decision test results in Table 2 represent mean raw scores. The results show developmental trends according to standard of education. For example, the mean correct rejections of nonpseudohomophones as being nonwords was 19.28 for the Std 1 subjects, 40.04 for the Std 3 subjects and 42.00 for the Std 5 subjects. The mean number of nonpseudohomophone errors made by Std 1 subjects was 5.29, 3.08 for Std 3 subjects, and 1.37 for Std 5 subjects.

Table 3 shows the mean scores and standard deviations for for complex and simple working memory variables for each standard. These test results also represent mean raw scores.

TABLE 3

Mean Scores and Standard Deviations obtained by Pilot Subjects on Working Memory Tests

| STD |      | WORKING MEMORY<br>READING SPAN | WORKING MEMORY<br>LISTENING SPAN | DIGIT SPAN | WORD SPAN | DOT COUNTING<br>SPAN |
|-----|------|--------------------------------|----------------------------------|------------|-----------|----------------------|
| 1   | MEAN | 17.56                          | 16.27                            | 5.05       | 5.38      | 4.20                 |
|     | SD   | 6.41                           | 5.45                             | 0.66       | 2.16      | 0.63                 |
| 3   | MEAN | 27.31                          | 27.58                            | 5.77       | 6.94      | 5.54                 |
|     | SD   | 6.93                           | 6.61                             | 0.50       | 1.91      | 1.01                 |
| 5   | MEAN | 27.76                          | 27.82                            | 6.28       | 7.44      | 4.76                 |
|     | SD   | 5.02                           | 5.54                             | 0.84       | 1.86      | 0.46                 |

WORKING MEMORY READING AND LISTENING SPAN:

The score on both tests was the number of cue words recorded in the correct sequence. The maximum possible score was 36. In each case, results for the Std 3 and 5 subjects were similar. These were 27.31 and 27.76 for the reading span test and 27.58 and 27.82 for the listening span test, respectively. This raised the possibility of a ceiling effect.

WORD SPAN:

The score represented the number of words correctly recorded out of 15 target words in List A. These scores showed developmental trends according to level of education. The mean for Std 1 subjects was 5.38, for Std 3 subjects, 6.94 and for Std 5 subjects, 7.44.

DIGIT SPAN:

This score was the number of digits correctly recorded in sequence. The maximum digit span was 8. These results also appear to show developmental trends according to level of education. The mean for Std 1 subjects was 5.05, for Std 3 subjects, 5.77 and for Std 5 subjects, 6.28.

#### DOT COUNTING SPAN:

The score was obtained from the card-set in which at least two of the three trials had numbers in the correct order. The total score was 5. The distribution of scores for this test again raised the possibility of a ceiling effect. The mean for Std 1 subjects was 4.28 and for Std 5 subjects, 4.78. It was decided to try including six- and seven-card sets on the Std 3 subjects, again after checking for further ceiling effects with some of the better Std 5 readers. Thereafter, the mean for Std 3 subjects was 5.54, which was higher than that of the Std 5 subjects on the five-card set.

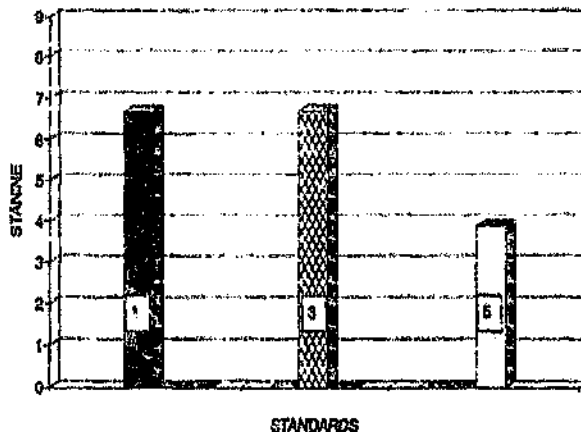
#### 5.4 DISCUSSION

The aim of the pilot study was to evaluate the test material to be used in the main study. Of the 90 children tested in each standard, it was hoped that about sixty children in each group would fall within the "average" stanine category for reading comprehension, the dependent variable. These children would then form the representative sample of "normal readers". However, this sample size was not found for any standard. Figure 6 shows the stanine distribution within the total Standard 1, 3 and 5 groups. Std 1 and 3 subjects scored higher than predicted resulting in a skewed distribution. The Std 5 subjects scored lower than predicted.

Difficulties were encountered with the test materials and procedures for certain tests. There was little differentiation between the groups with regard to their performance on the silent tests of phonology. However, although the younger children made almost as many correct phonological judgements as the older children,



they had taken longer to complete the tests. Consequently, a time limit of 20-second was felt to be advisable to enable the developmental assessment of phonological coding efficiency and speed of nonlexical access. These skills would be automatic in the older children, and therefore, they would complete more items within the time limit compared with the younger children.



**FIGURE 6**  
**Mean Stanines on Reading Comprehension Tests in the Pilot Study**

The working memory reading and listening span tests showed ceiling effects in some of the older children, who managed to recall some cue words in the correct order in all the four sentence trials. Furthermore, cheating was a problem during this test. The children had pencils in their hands during the acquisition phase as they were required to mark whether the sentences made sense or not. This tempted some subjects to jot down both the cue words instead of remembering them. To prevent this from contaminating the data in the main

study, this sense/nonsense judgement was omitted. Thereafter, the children sat with their hands on their heads while reading or listening to the sentences. In addition, extra sentences were used for the main study and the number of trials were reduced to three per sentence-series.

Many of the Std 5 and some of the Std 3 children showed ceiling effects on the dot counting test. Extra card-sets were added for the main study to evaluate memory performance during this test.

Thus, some of the test materials and procedures were unsatisfactory. These anomalies were rectified for use in the main study.

CHAPTER 6  
WORKING MEMORY IN READING : MAIN STUDY

6.1 METHODS

6.1.1 Research Design

The same nonexperimental research design used in the pilot study was again applied. The dependent and independent variables remained unchanged (see 5.2.1).

6.1.2 Subjects

A total of 480 English-speaking Std 1, 3, and 5 pupils were tested in Transvaal Education Department Primary Schools and were used as a pool for the selection of subjects. This number included 132 normal pilot study subjects who were retested on the measures that had been improved or amended. This will be discussed below in detail. A further 67 subjects were selected from the additional children using the same selection criteria (see 5.2.2). This increased the total number of subjects in the main study to 199. The subjects were divided into three groups according to their standard of education. There were 64 Std 1, 75 Std 3 and 60 Std 5 pupils (see Table 4). The average ages were 9.03, 10.90 and 12.99 years, respectively.

TABLE 4  
Subjects included in the Main Study

| STANDARD | N  | MEAN AGE |
|----------|----|----------|
| 1        | 64 | 9.03     |
| 3        | 75 | 10.90    |
| 5        | 60 | 12.99    |

### 6.1.3 Materials

In the main study, the same battery of tests was used as was administered in the pilot study to assess the reading, language and memory skills. These included the following tests: reading and listening comprehension, vocabulary, silent tests of phonology, lexical decision, word span and digit span. Details of these materials can be found in 5.2.3. However, changes were made to the following:

#### WORKING MEMORY READING SPAN TEST:

Extra sentences were included in the practice and test series of short sentences and these were randomly rearranged. The new sentences complied with the subject (either an animal or a person), verb and object format. The number of sentences in the test series was increased from four to seven (see Appendices T to U).

#### WORKING MEMORY LISTENING SPAN TEST:

Practice and test series of short sentences similar to those presented during the reading span test were constructed as described above. The number of sentences in a series was also increased from four to seven (see Appendices W to X).

#### DOT COUNTING SPAN TEST:

The number of card sets used was increased from 15 to 21 sets and were also randomly rearranged. They ranged from one to seven cards in number in a set. There were three trials for each set (see Appendices Zi and ii).

### 6.1.4 Procedure

Modifications were also made to improve test administration procedures. The children were asked to

place their hands on their heads during all listening and working memory tests, thereby removing the temptation to jot answers down surreptitiously. This greatly improved the face validity of the results. Other changes included the following:

#### SILENT TESTS OF PHONOLOGY:

Instructions were the same as before. However, a 10-second practice list was introduced as well as a time limit of 20 seconds for each test list irrespective of standard of education. All the children started and stopped working at the same time. The lists were not completed after the time limit had elapsed.

#### WORKING MEMORY READING SPAN TEST:

There were six different series of two to seven sentences each. Therefore, the maximum score increased from 36 to 81. Each series was presented three times so that the children read and remembered three sets of two sentences, three sets of three sentences, etc. The sentences were presented in the same way as in the pilot study. However, the children were no longer required to judge and record whether a sentence made sense or not to obviate cheating during the acquisition phases of these tests.

#### WORKING MEMORY LISTENING SPAN TEST:

The procedure was similar to that of the Reading Span Test. However, instead of reading the sentences, the children listened while the sentences were read to them.

#### DOT COUNTING SPAN TEST:

The cards were presented as specified in the pilot study. However, the number of cards in a set increased from one to seven. The maximum score was, therefore, 7.

## CHAPTER 7 MAIN STUDY RESULTS

### 7.1 INTRODUCTION

Tests of working memory, reading and basic language skills were used in the main study to assess the Std 1, 3 and 5 subjects. The working memory measures included simple digit, word and dot span tests and complex reading and listening span tests. Both component reading skills, namely phonological and orthographic knowledge, and reading comprehension were tested. The language tests included measures of vocabulary and listening comprehension. The data were collected and scored in the same way as in the pilot study (see section 5.2) and further Lotus 123 spread sheets were compiled. Subjects were again selected once the data had been sorted according to reading comprehension stanines. Results from the pilot and main studies were then combined according to standard of education. Plots were performed comparing each variable with the others using a statistical software package (SAS Institute Inc., 1990) to identify subjects with anomalous results. These subjects were then excluded from the final subject groups as their scores might contaminate the results. Initially, the variables used in the main study were similar to those in the pilot study:

#### Dependent variable

- The percentile obtained on standardized HSRC Std 1, 3 and 5 reading comprehension tests. This percentile was based on the total number of questions answered correctly by the subjects.

### Independent variables

- The percentiles obtained on the HSRC Std 1, 3 and 5 listening comprehension and vocabulary tests, representing the number of questions answered correctly in the respective tests.
- The number of rhyming and nonrhyming word-pairs correctly identified within the 20-second time limit during the regular and irregular word and nonword subtests of the silent tests of phonology.
- The number of items correctly identified within the 20-second time limit as real words, nonpseudo-homophones and pseudohomophones during the lexical decision tests of orthographic knowledge.
- The total number of nonpseudohomophonous and pseudohomophonous errors made on the relevant lexical decision tests.
- The total number of subjects or objects recalled in the correct sequence during complex reading and listening span working memory tests.
- The total number of items recalled correctly during the simple working memory word span test.
- The highest number of items recalled in the correct sequence during the simple working memory word, digit and dot counting span tests.

During the course of data analysis it became clear that the listening comprehension, vocabulary, phonology and orthographic independent variables acted as mediators in certain circumstances. This was evident from the indirect relationships between the working memory independent variables and the dependent variable, reading comprehension, and their direct relationship with the "mediating variables". The latter, in turn, had direct relationships with the dependent variable. Therefore, in order to use the above model for analytical and inferential purposes, the independent

variables were reorganized as follows:

Mediating variables

- The percentiles obtained on the HSRC Std 1, 3 and 5 listening comprehension and vocabulary tests, representing the number of questions answered correctly in the respective tests.
- The number of rhyming and nonrhyming word-pairs correctly identified within the 20-second time limit during the regular and irregular word and nonword subtests of the silent tests of phonology.
- The number of items correctly identified within the 20-second time limit as real words, nonpseudo-homophones and pseudohomophones during the lexical decision tests of orthographic knowledge.
- The total number of nonpseudohomophonous and pseudohomophonous errors made on the relevant lexical decision tests.

Independent variables

- The total number of subjects or objects recalled in the correct sequence during complex reading and listening span working memory tests.
- The total number of items recalled correctly during the simple working memory word span test.
- The highest number of items recalled in the correct sequence during the simple working memory word, digit and dot counting span tests.

The data were analysed for within- and between-group differences. Descriptive statistical analyses, including means, standard deviations and correlations were calculated and resultant developmental trends in working memory and reading skills statistically investigated by analysis of variance. Thereafter, regression analyses were carried out to clarify the



contribution made by working memory to component reading skills, other language variables, namely listening comprehension and vocabulary, and reading comprehension in children. These analyses were performed using standard software (CSS StatSoft, 1988; SAS Institute Inc., 1990).

## 7.2 STATISTICAL ANALYSIS RESULTS

### 7.2.1 General Descriptive Statistics

Table 5 shows the mean scores and standard deviations for reading and language variables for each standard. The reading and listening comprehension, and vocabulary tests were standardized for each group, and results were expressed as mean percentiles. Developmental trends could, therefore, not be assessed for these variables.

TABLE 5

Mean Scores and Standard Deviations obtained by Subjects in the Main Study for Reading and Language Tests

| STD | READING COMPREHENSION | VOCABULARY | LISTENING COMPREHENSION | SILENT TESTS OF PHONOLOGY |                 |          | LEXICAL DECISION TESTS |                      |                   |                   |
|-----|-----------------------|------------|-------------------------|---------------------------|-----------------|----------|------------------------|----------------------|-------------------|-------------------|
|     |                       |            |                         | REGULAR WORDS             | IRREGULAR WORDS | NONWORDS | NONPSEUDO-WORDPHONES   | NONPSEUDO-WORDPHONES | PSEUDO-DOMOPHONES | PSEUDO-DOMOPHONES |
| 1   | MEAN 52.45            | 50.25      | 48.63                   | 14.18                     | 14.01           | 13.32    | 19.11                  | 5.84                 | 18.80             | 9.96              |
|     | SD 15.07              | 14.07      | 15.24                   | 4.54                      | 4.93            | 4.55     | 6.80                   | 4.28                 | 6.65              | 5.02              |
| 3   | MEAN 46.96            | 45.53      | 54.60                   | 27.18                     | 24.94           | 22.53    | 16.61                  | 2.60                 | 34.73             | 4.41              |
|     | SD 15.04              | 23.57      | 10.51                   | 6.88                      | 6.11            | 6.21     | 7.14                   | 2.13                 | 6.78              | 3.03              |
| 5   | MEAN 44.06            | 56.30      | 36.86                   | 33.47                     | 31.80           | 29.15    | 43.30                  | 0.96                 | 3.14              | 2.82              |
|     | SD 13.69              | 20.57      | 20.80                   | 5.32                      | 6.81            | 7.34     | 6.82                   | 1.03                 | 0.41              | 2.64              |
| All | MEAN 47.83            | 50.32      | 53.63                   | 25.33                     | 24.60           | 21.93    | 33.15                  | 3.14                 | 31.52             | 5.00              |
|     | SD 14.37              | 21.37      | 21.93                   | 9.72                      | 9.58            | 8.91     | 12.08                  | 3.41                 | 10.83             | 6.77              |

The mean percentiles achieved for reading comprehension by the Std 1, 3 and 5 subjects were 52.45, 46.96 and 44.06 respectively. These percentiles are equivalent to a stanine of 5 (range 40 to 59), which is classified as average. A similar pattern can be seen in the mean percentiles achieved for vocabulary (Std 1: 50.25, Std

3: 45.55 and Std 5: 56.38) and again, they are equivalent to a stanine of 5. With regard to the listening comprehension, the mean percentile obtained by Std 1 (68.69), Std 3 (54.60) and Std 5 (36.86) subjects fell within the 6th (60 to 76), 5th (40 to 59) and 4th (23 to 39) stanine ranges respectively. However, all these stanines are classified as average.

The results of the silent tests of phonology (regular and irregular word and nonword rhyming judgements) and the lexical decision tests (word vs. nonword [nonpseudohomophones and pseudohomophones] discrimination and nonpseudohomophone and pseudohomophone errors) in Table 5 represent mean raw scores. The same tests were used for all subjects, and the results show developmental trends according to standard of education.

One-way analyses of variance were performed to assess these trends, and they are illustrated in Figures 7 to 9. The results showed an significant increase in the mean number of correct regular ( $F=135.17$ ,  $df=2$ ,  $p < .001$ ) and irregular word ( $F=126.31$ ,  $df=2$ ,  $p < .001$ ) and nonword ( $F=76.40$ ,  $df=2$ ,  $p < .001$ ) rhyming judgements made by the Std 1, Std 3 and Std 5 subjects (see Figure 7). Post hoc analysis using the Tukey (HSD) test indicated that the performance differences between the standards were significant for all the silent tests of phonology ( $p < .05$ ). Comparisons of the significant differences using 2-Tailed t-tests showed the following:

Regular words: Std 1 vs. Std 3 ( $t=-6.49$ ,  $df=74$ ,  
 $p < .001$ )  
Std 1 vs. Std 5 ( $t=-17.09$ ,  $df=96$ ,  
 $p < .001$ )

Std 3 vs. Std 5 ( $t=-8.58$ ,  $df=79$ ,  
 $p < .001$ )

Irregular words: Std 1 vs. Std 3 ( $t=-7.13$ ,  $df=74$ ,  
 $p < .001$ )

Std 1 vs. Std 5 ( $t=-14.63$ ,  $df=96$ ,  
 $p < .001$ )

Std 3 vs. Std 5 ( $t=-6.47$ ,  $df=79$ ,  
 $p < .001$ )

Nonwords: Std 1 vs. Std 3 ( $t=-5.22$ ,  $df=74$ ,  
 $p < .001$ )

Std 1 vs. Std 5 ( $t=-11.91$ ,  $df=96$ ,  
 $p < .001$ )

Std 3 vs. Std 5 ( $t=-5.67$ ,  $df=79$ ,  
 $p < .001$ )

The Std 1 subjects showed no significant differences in performance between all the silent tests of phonology (regular vs. irregular words:  $t=1.14$ ,  $df=44$ , ns; regular words vs. nonwords:  $t=1.63$ ,  $df=44$ , ns; irregular words vs. nonwords:  $t=.52$ ,  $df=44$ , ns). The Std 3 subjects showed no significant differences in performance between on the regular and irregular words ( $t=0.32$ ,  $df=64$ , ns). However, the differences between regular words and nonwords ( $t=7.31$ ,  $df=64$ ,  $p < .001$ ) and irregular words and nonwords ( $t=6.82$ ,  $df=64$ ,  $p < .001$ ) were significant, indicating that they were poorer at making nonword rhyming judgements than regular or irregular rhyming judgements. The Std 5 subjects showed significant differences in performance between all the silent tests of phonology (regular vs. irregular words:  $t=3.22$ ,  $df=50$ ,  $p < .01$ ; regular words vs. nonwords:  $t=6.81$ ,  $df=50$ ,  $p < .001$ ; irregular words vs. nonwords:  $t=4.93$ ,  $df=50$ ,  $p < .001$ ). These subjects were best at making regular rhyming judgements, followed by

irregular and then nonwords rhyming judgements.

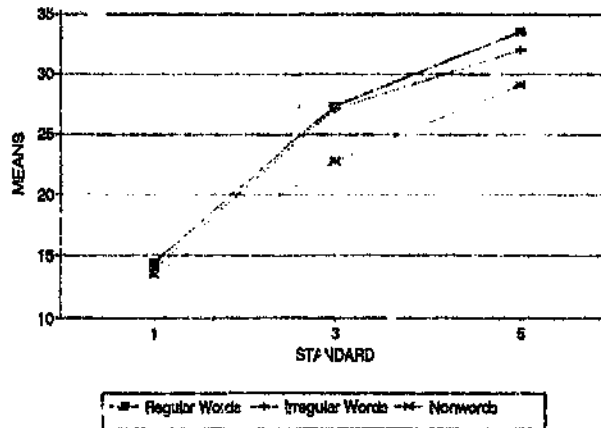


FIGURE 7

Developmental Changes in Results of the Silent Tests of Phonology for Regular and Irregular Word and Nonword Rhyming Judgements. The means are the average number of correct rhyming judgements.

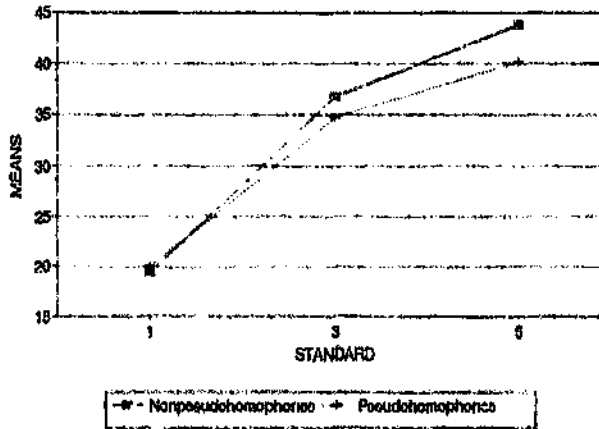
The ability to distinguish between words and nonwords according to orthographic rules also increased significantly according to level of education between all standards (words vs. nonpseudohomophones :  $F=164.43$ ,  $df=2$ ,  $p < .001$  and words vs. pseudohomophones :  $F=116.73$ ,  $df=2$ ,  $p < .001$ ) (Tukey [HSD],  $p < .05$ ) (see Figure 8). Comparisons of these significant differences using 2-Tailed t-tests showed the following:

Words vs. non- : Std 1 vs. Std 3 ( $t=-8.19$ ,  $df=74$ ,  
pseudohomophones  $p < .001$ )

Std 1 vs. Std 5 ( $t=-18.80$ ,  $df=96$ ,  
 $p < .001$ )

Std 3 vs. Std 5 ( $t=-8.78$ ,  $df=79$ ,  
 $p < .001$ )

Words vs. : Std 1 vs. Std 3 ( $t=-8.04$ ,  $df=74$ ,  
 pseudohomophones  $p < .001$ )  
 Std 1 vs. Std 5 ( $t=-14.00$ ,  $df=96$ ,  
 $p < .001$ )  
 Std 3 vs. Std 5 ( $t=-5.52$ ,  $df=79$ ,  
 $p < .001$ )



**FIGURE 8**  
 Developmental Changes in Results of the Lexical Decision Tests of Orthography. The means are the average number of correct discriminations between words and pseudohomophones and nonpseudohomophones.

The Std 1 subjects showed no significant differences in the ability to discriminate between words and the two kinds of nonwords, namely nonpseudohomophones and pseudohomophones ( $t=-.51$ ,  $df=44$ , ns). The Std 3 and Std 5 subjects were significantly better at distinguishing between words versus nonpseudohomophones than words versus pseudohomophones (Std 3:  $t=3.49$ ,  $df=64$ ,  $p < .001$ ; Std 5:  $t=5.90$ ,  $df=50$ ,  $p < .001$ ). There were inverse decreases in the number of nonpseudohomophone ( $F=60.75$ ,  $df=2$ ,  $p < .001$ ) and pseudohomophone ( $F=74.49$ ,  $df=2$ ,  $p$

<.001) errors (see Figure 9) with significant differences between all standards (Tukey [HSD],  $p < .05$ ). Comparisons of these significant differences using 2-Tailed t-tests showed the following:

Nonpseudohomophone errors : Std 1 vs. Std 3 ( $t=3.90$ ,  $df=74$ ,  $p < .001$ )

Std 1 vs. Std 5 ( $t=8.50$ ,  $df=96$ ,  $p < .001$ )

Std 3 vs. Std 5 ( $t=4.76$ ,  $df=79$ ,  $p < .001$ )

Pseudohomophone errors : Std 1 vs. Std 3 ( $t=4.80$ ,  $df=74$ ,  $p < .001$ )

Std 1 vs. Std 5 ( $t=8.30$ ,  $df=96$ ,  $p < .001$ )

Std 3 vs. Std 5 ( $t=2.71$ ,  $df=79$ ,  $p < .01$ )

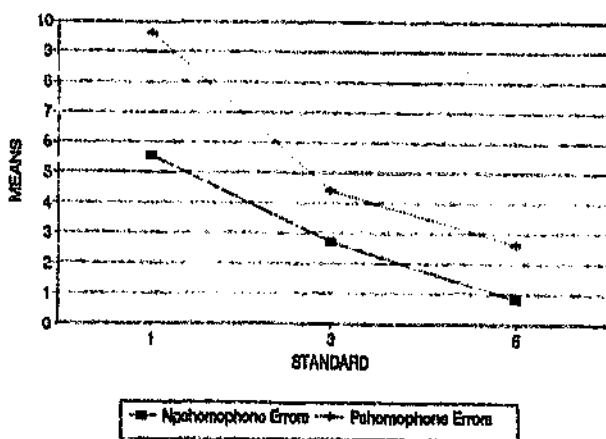


FIGURE 9

Developmental Changes in Results of Nonpseudohomophone and Pseudohomophone Lexical Errors. The means are the average number of errors.

The Std 1, 3 and 5 subjects all made significantly more pseudohomophone than nonpseudohomophone errors (Std 1:  $t=-6.63$ ,  $df=44$ ,  $p < .001$ ; Std 3:  $t=-5.05$ ,  $df=64$ ,  $p < .001$ ; Std 5:  $t=-5.61$ ,  $df=50$ ,  $p < .001$ ).

Table 6 shows the mean scores and standard deviations for complex and simple working memory variables for each standard. These test results also represent mean raw scores and, with the exception of the dot counting span test, show significant developmental trends.

TABLE 6  
Mean Scores and Standard deviations obtained by Subjects in the Main Study for Working Memory Tests

| STD |      | WORKING MEMORY | WORKING MEMORY | DIGIT SPAN | WORD SPAN | DOT COUNTING SPAN |
|-----|------|----------------|----------------|------------|-----------|-------------------|
|     |      | READING SPAN   | LISTENING SPAN |            |           |                   |
| 1   | MEAN | 17.96          | 15.03          | 5.29       | 5.60      | 4.63              |
|     | SD   | 7.32           | 6.46           | 0.66       | 1.02      | 0.81              |
| 3   | MEAN | 29.93          | 20.45          | 5.82       | 6.75      | 5.62              |
|     | SD   | 7.47           | 0.38           | 0.64       | 1.74      | 0.94              |
| 5   | MEAN | 34.69          | 21.12          | 6.28       | 7.81      | 5.97              |
|     | SD   | 9.65           | 7.90           | 0.78       | 2.12      | 0.90              |
| All | MEAN | 27.79          | 25.09          | 5.79       | 6.65      | 5.31              |
|     | SD   | 10.56          | 10.26          | 0.79       | 2.10      | 1.02              |

The Std 5 subjects recalled more target subject or object words ( $x = 34.69$ ) during the complex reading span test ( $F= 45.09$ ,  $df=2$ ,  $p < .001$ ) than the Std 1 ( $x = 17.96$ ) and Std 3 subjects ( $x = 29.93$ ). These developmental differences (see Figure 10) were found to be significant between the Std 1 and 3, and Std 1 and 5 subjects using the Tukey (HSD) test ( $p < .05$ ). Significant developmental differences obtained for the complex listening span test ( $F=53.38$ ,  $df=2$ ,  $p < .001$ ) can also be ascribed to differences between Std 1 ( $x = 15.08$ ) and Std 3, and Std 1 and Std 5 subjects (Tukey

(HSD),  $p < .05$ ). Comparisons of these significant differences using 2-Tailed t-tests showed the following:

Reading Span : Std 1 vs. Std 3 ( $t=-7.12$ ,  $df=74$ ,  
 $p < .001$ )  
Std 1 vs. Std 5 ( $t=-9.27$ ,  $df=96$ ,  
 $p < .001$ )

Listening Span : Std 1 vs. Std 3 ( $t=-7.34$ ,  $df=74$ ,  
 $p < .001$ )  
Std 1 vs. Std 5 ( $t=-10.98$ ,  $df=96$ ,  
 $p < .001$ )

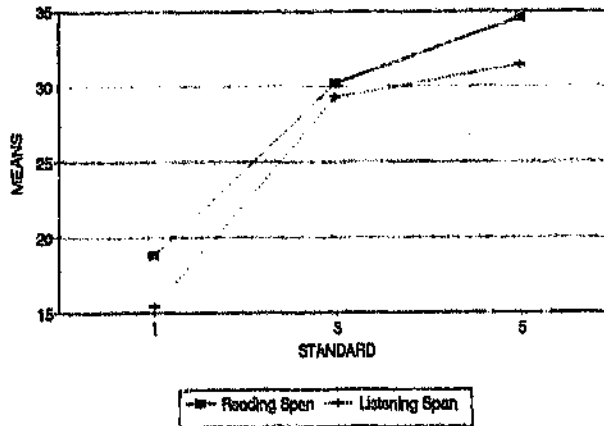


FIGURE 10

Developmental Changes in Results of the Complex Working Memory Reading and Listening Span Tests. The means are the average number of items recalled in the correct order.

Differences between Std 3 and Std 5 subjects on the complex reading span for recalling target subject or object words were not significant ( $t=-1.29$ ,  $df=79$ , ns). There were also no significant differences between the Std 3 ( $x = 28.46$ ) and Std 5 subjects ( $x = 31.12$ ) on the



recall of target subject or object words on the complex listening span test ( $t=-1.05$ ,  $df=79$ , ns). None of the differences between reading and listening span results within the Std 1, 3 and 5 groups were significant (Std 1:  $t=3.28$ ,  $df=44$ , ns; Std 3:  $t=1.11$ ,  $df=64$ , ns; Std 5:  $t=2.62$ ,  $df=50$ , ns).

Recall for digits ( $x = 6.28$ ) and words ( $x = 7.81$ ) was superior in the Std 5 subjects compared with both the Std 3 (digits  $x = 5.82$ ; words  $x = 6.75$ ) and Std 1 subjects (digits  $x = 5.29$ ; words  $x = 5.40$ ) during the simple digit ( $F=22.31$ ,  $df=2$ ,  $p < .001$ ) and word ( $F=13.42$ ,  $df=2$ ,  $p < .001$ ) span tests. These developmental differences were significant for all standards for the digit span test (Tukey [HSD]  $p < .05$ ) With regard to the word span test, the developmental differences occurred between the Std 1 and Std 5, and Std 3 and Std 5 subjects. The Std 3 ( $x = 5.62$ ) and Std 5 subjects ( $x = 5.57$ ) recalled a similar number of dots during the dot counting span whereas the Std 1 subjects only recalled a mean of 4.63 dots. Nevertheless, these results still showed a positive developmental increase between the Std 1 and 3, and Std 1 and 5 subjects ( $F=14.94$ ,  $df=2$ ,  $p < .001$ ) (see Figure 11). Comparisons of these significant differences using 2-Tailed t-tests showed the following:

Digit Span : Std 1 vs. Std 3 ( $t=-2.65$ ,  $df=74$ ,  $p < .01$ )  
Std 1 vs. Std 5 ( $t=-6.83$ ,  $df=96$ ,  $p < .001$ )  
Std 3 vs. Std 5 ( $t=-2.69$ ,  $df=79$ ,  $p < .01$ )

Word Span : Std 1 vs. Std 5 ( $t=-5.44$ ,  $df=96$ ,  $p < .001$ )  
Std 3 vs. Std 5 ( $t=-3.21$ ,  $df=79$ ,  $p < .01$ )

Dot Counting: Std 1 vs. Std 3 ( $t=-5.16$ ,  $df=74$ ,  $p < .001$ )  
Span Std 1 vs. Std 5 ( $t=-5.24$ ,  $df=96$ ,  $p < .001$ )

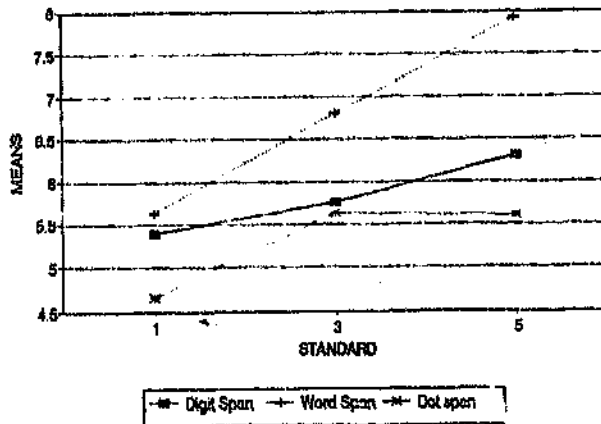


FIGURE 11

Developmental Changes in Results of the Digit, Word and Dot Counting Span Tests. The means are the number of items correctly recalled.

The Std 1 subjects recalled fewer dots than either digits ( $t=5.45$ ,  $df=44$ ,  $p < .001$ ) or words ( $t=3.36$ ,  $df=44$ ,  $p < .01$ ). Immediate memory span for words was superior to that of digits ( $t=-4.63$ ,  $df=64$ ,  $p < .001$ ) and dots ( $t=4.78$ ,  $df=64$ ,  $p < .001$ ) for the Std 3 subjects. However, their immediate memory span for digits and dots did not differ significantly ( $t=1.20$ ,  $df=64$ , ns). Immediate word span was superior to digit ( $t=-5.28$ ,  $df=50$ ,  $p < .001$ ) and dot counting span ( $t= 7.18$ ,  $df=50$ ,  $p < .001$ ), and digit span, in turn, was superior to dot counting span ( $t=4.17$ ,  $df=50$ ,  $p < .001$ ) in the Std 5 subjects.

### 7.2.2 Correlations

Pearson Product Moment correlation coefficients were first calculated between all variables for Std 1, 3, and 5 subjects separately. Correlation matrices are shown in Tables 7, 8, 9. Significant trends within

standards, which might not be reflected in the combined group, were analysed. However, subdividing the subjects according to standards would have partialled out the effects of level of education, thereby limiting the range of each measure and possibly attenuating other important correlations. Therefore, the subjects were also analysed as a combined group and these correlation matrices are shown in Tables 10 and 11.

The working memory reading and listening span tests were designed to tap the storage and processing functions of working memory. The results indicate that the only significant correlations between reading comprehension and reading span ( $r=.27$ ,  $p < .05$ ), and between listening comprehension and listening span ( $r=.29$ ,  $p < .05$ ) occurred within the Std 1 subject group.

The pattern of significant correlations between working memory tests and reading and language tests varied depending on the subject groups. Within standards, word span correlated significantly with phonological judgements of regular word-pairs for Std 1 ( $r=.42$ ,  $p < .01$ ) and Std 3 subjects ( $r=.32$ ,  $p < .01$ ), but not for the Std 5 subjects ( $r = -.01$ , ns). Word span also correlated with listening comprehension ( $r=.31$ ,  $p < .01$ ) and phonological judgement of irregular word-pairs ( $r=.29$ ,  $p < .01$ ) for Std 3 subjects.

Reading and listening span working memory results correlated significantly within groups (Std 1:  $r=.55$ ,  $p < .001$ ; Std 3:  $r=.64$ ,  $p < .001$ ; Std 5:  $r=.56$ ,  $p < .001$ , respectively). With regard to other relationships between the complex and simple, traditional working memory tests, the dot counting span correlated with reading span within groups (Std 1:  $r=.29$ ,  $p < .05$ ; Std

TABLE 7

Pearson Product-Moment Correlations : Standard I Subjects

| CORRELATION COEFFICIENT   | AGE   | HC     | VOC    | LC    | REG    | IRX    | NW     | WPM    | WPM-ERR | PM     | PM-ERR | WM-DS | WM-LS | WM-DS | WM-MS |
|---------------------------|-------|--------|--------|-------|--------|--------|--------|--------|---------|--------|--------|-------|-------|-------|-------|
| PROBABILITY               |       |        |        |       |        |        |        |        |         |        |        |       |       |       |       |
| READING                   | 0.07  |        |        |       |        |        |        |        |         |        |        |       |       |       |       |
| COMPREHENSION (AC)        | 0.845 |        |        |       |        |        |        |        |         |        |        |       |       |       |       |
| VOCABULARY (VOC)          | -0.02 | 0.57c  |        |       |        |        |        |        |         |        |        |       |       |       |       |
|                           | 0.905 | 0.001  |        |       |        |        |        |        |         |        |        |       |       |       |       |
| LISTENING                 | -0.13 | 0.35b  | 0.35b  |       |        |        |        |        |         |        |        |       |       |       |       |
| COMPREHENSION (LC)        | 0.332 | 0.025  | 0.005  |       |        |        |        |        |         |        |        |       |       |       |       |
| PHONOLOGY                 | -0.28 | 0.60c  | 0.25   | 0.18  |        |        |        |        |         |        |        |       |       |       |       |
| REGULAR WORDS (REG)       | 0.027 | 0.001  | 0.057  | 0.184 |        |        |        |        |         |        |        |       |       |       |       |
| PHONOLOGY                 | -0.18 | 0.500  | 0.36b  | 0.20  | 0.71c  |        |        |        |         |        |        |       |       |       |       |
| IRREGULAR WORDS (IRR)     | 0.182 | 0.001  | 0.007  | 0.166 | 0.001  |        |        |        |         |        |        |       |       |       |       |
| PHONOLOGY                 | 0.24  | 0.62c  | 0.47c  | 0.17  | 0.75c  | 0.82c  |        |        |         |        |        |       |       |       |       |
| SCHEMATA (SM)             | 0.084 | 0.001  | 0.001  | 0.207 | 0.001  | 0.001  |        |        |         |        |        |       |       |       |       |
| NONPSEUDOMORPHOLOGY (NPM) | -0.17 | 0.53c  | 0.27a  | 0.05  | 0.58c  | 0.58c  | 0.62c  |        |         |        |        |       |       |       |       |
|                           | 0.197 | 0.001  | 0.015  | 0.713 | 0.001  | 0.001  | 0.001  |        |         |        |        |       |       |       |       |
| NONPSEUDOMORPHOLOGY (NPM) | 0.03  | -0.44c | -0.28a | -0.09 | -0.45c | -0.56c | -0.41b | -0.53c |         |        |        |       |       |       |       |
| PARADIGMS (PAR)           | 0.795 | 0.001  | 0.033  | 0.510 | 0.001  | 0.001  | 0.001  | 0.001  |         |        |        |       |       |       |       |
| PARADIGMS (PAR)           | -0.16 | 0.51c  | 0.19a  | 0.19  | 0.54c  | 0.67c  | 0.62c  | 0.77c  | -0.17c  |        |        |       |       |       |       |
|                           | 0.241 | 0.001  | 0.012  | 0.184 | 0.001  | 0.001  | 0.001  | 0.001  | 0.001   |        |        |       |       |       |       |
| PARADIGMS (PAR)           | 0.02  | -0.59c | -0.42c | -0.20 | -0.42b | -0.47c | -0.37b | -0.49c | 0.59c   | -0.61c |        |       |       |       |       |
| PARADIGMS (PAR)           | 0.094 | 0.001  | 0.001  | 0.192 | 0.001  | 0.001  | 0.001  | 0.001  | 0.001   | 0.001  |        |       |       |       |       |
| WORKING MEMORY            | 0.06  | 0.27a  | 0.09   | 0.22  | 0.08   | 0.22   | 0.19   | 0.20   | -0.10   | 0.30a  | -0.11  |       |       |       |       |
| HEADING SPAN (HM-DS)      | 0.654 | 0.050  | 0.320  | 0.094 | 0.554  | 0.108  | 0.154  | 0.157  | 0.200   | 0.031  | 0.448  |       |       |       |       |
| WORKING MEMORY            | 0.03  | 0.05   | 0.21   | 0.39a | -0.01  | -0.01  | -0.04  | -0.07  | 0.05    | 0.03   | 0.01   | 0.55c |       |       |       |
| LISTENING SPAN (LM-LS)    | 0.831 | 0.567  | 0.122  | 0.028 | 0.821  | 0.851  | 0.760  | 0.624  | 0.708   | 0.805  | 0.942  | 0.001 |       |       |       |
| WORKING MEMORY            | 0.28  | 0.08   | 0.09   | -0.03 | 0.07   | -0.02  | 0.12   | -0.09  | -0.01   | -0.11  | -0.04  | 0.13  | 0.05  |       |       |
| EIGHT SPAN (EM-DS)        | 0.076 | 0.324  | 0.484  | 0.801 | 0.447  | 0.873  | 0.378  | 0.507  | 0.855   | 0.408  | 0.755  | 0.367 | 0.733 |       |       |
| WORKING MEMORY            | 0.01  | 0.17   | 0.07   | 0.13  | 0.41   | 0.70   | 0.12   | 0.17   | -0.11   | 0.22   | -0.22  | 0.20  | 0.24  | 0.13  |       |
| WORD SPAN (WM-MS)         | 0.355 | 0.188  | 0.391  | 0.304 | 0.007  | 0.161  | 0.291  | 0.191  | 0.420   | 0.108  | 0.105  | 0.165 | 0.079 | 0.314 |       |
| WORKING MEMORY            | 0.10  | 0.05   | -0.04  | 0.05  | 0.21   | 0.07   | 0.03   | 0.01   | 0.01    | 0.04   | -0.14  | 0.29  | 0.23  | 0.26  | 0.24  |
| DOT SPAN (DM-DS)          | 0.447 | 0.487  | 0.795  | 0.695 | 0.134  | 0.627  | 0.820  | 0.944  | 0.987   | 0.772  | 0.324  | 0.014 | 0.088 | 0.056 | 0.075 |

Key : a = p &lt; 0.05 ; b = p &lt; 0.01 ; c = p &lt; 0.001

TABLE 8

Pearson Product-Moment Correlations: Standard 3 Subjects

| CORRELATION COEFFICIENT | MR     | RC     | VOC    | LC     | REG    | KRR   | NS    | MPH   | MPH-ERR | PSH    | PSH-ERR | WM-NS | WM-LC | WM-DB | WM-VE |
|-------------------------|--------|--------|--------|--------|--------|-------|-------|-------|---------|--------|---------|-------|-------|-------|-------|
| PROBABILITY             |        |        |        |        |        |       |       |       |         |        |         |       |       |       |       |
| READING                 | -0.23a |        |        |        |        |       |       |       |         |        |         |       |       |       |       |
| COMPREHENSION (EC)      | 0.043  |        |        |        |        |       |       |       |         |        |         |       |       |       |       |
| VOCABULARY (VOC)        | -0.15  | 0.39c  |        |        |        |       |       |       |         |        |         |       |       |       |       |
|                         | 0.191  | 0.001  |        |        |        |       |       |       |         |        |         |       |       |       |       |
| LISTENING               | 0.11   | 0.41c  | 0.29a  |        |        |       |       |       |         |        |         |       |       |       |       |
| COMPREHENSION (LC)      | 0.340  | 0.001  | 0.013  |        |        |       |       |       |         |        |         |       |       |       |       |
| PHONOLOGY               | 0.02   | 0.19   | 0.19   | 0.34b  |        |       |       |       |         |        |         |       |       |       |       |
| REGULAR WORDS (REG)     | 0.079  | 0.11b  | 0.119  | 0.004  |        |       |       |       |         |        |         |       |       |       |       |
| PHONOLOGY               | 0.04   | 0.31b  | 0.08   | 0.85b  | 0.00c  |       |       |       |         |        |         |       |       |       |       |
| IRREGULAR WORDS (IRR)   | 0.745  | 0.007  | 0.629  | 0.007  |        |       |       |       |         |        |         |       |       |       |       |
| PHONOLOGY               | 0.06   | 0.23   | 0.21   | 0.34b  | 0.72c  | 0.66c |       |       |         |        |         |       |       |       |       |
| SPONSORS (SP)           | 0.597  | 0.060  | 0.285  | 0.004  | 0.001  | 0.001 |       |       |         |        |         |       |       |       |       |
| PSEUDOPHONOLOGY         | 0.01   | 0.24a  | 0.26a  | 0.20   | 0.58c  | 0.60c | 0.44c |       |         |        |         |       |       |       |       |
| (LPS)                   | 0.335  | 0.038  | 0.224  | 0.094  | 0.001  | 0.001 | 0.001 |       |         |        |         |       |       |       |       |
| PSEUDOPHONOLOGY         | 0.34a  | -0.24a | -0.25a | -0.25a | -0.03  | -0.04 | -0.02 | -0.07 |         |        |         |       |       |       |       |
| ERRORS (PSH-ERR)        | 0.042  | 0.039  | 0.035  | 0.022  | 0.024  | 0.721 | 0.852 | 0.542 |         |        |         |       |       |       |       |
| PSEUDOPHONOLOGY (PSH)   | -0.04  | 0.24a  | 0.27a  | 0.17   | 0.55c  | 0.51c | 0.35b | 0.78c | -0.02   |        |         |       |       |       |       |
|                         | 0.747  | 0.038  | 0.022  | 0.158  | 0.001  | 0.001 | 0.001 | 0.001 | 0.562   |        |         |       |       |       |       |
| PSEUDOPHONOLOGY         | 0.38b  | -0.42c | -0.35b | -0.29a | -0.26a | -0.21 | -0.19 | -0.10 | 0.47c   | -0.23a |         |       |       |       |       |
| ERRORS (PSH-ERR)        | 0.010  | 0.001  | 0.003  | 0.012  | 0.032  | 0.007 | 0.110 | 0.397 | 0.001   | 0.048  |         |       |       |       |       |
| WORKING MEMORY          | 0.11   | -0.18  | 0.02   | -0.09  | -0.07  | 0.04  | -0.11 | 0.11  | 0.01    | -0.05  |         |       |       |       |       |
| READING SPAN (WM-NS)    | 0.343  | 0.283  | 0.883  | 0.475  | 0.247  | 0.549 | 0.764 | 0.347 | 0.355   | 0.959  | 0.674   |       |       |       |       |
| WORKING MEMORY          | 0.04   | 0.10   | 0.17   | 0.17   | 0.23   | 0.18  | 0.14  | 0.01  | 0.14    | 0.09   | -0.11   | 0.64c |       |       |       |
| LISTENING SPAN (WM-LC)  | 0.770  | 0.404  | 0.165  | 0.166  | 0.060  | 0.147 | 0.235 | 0.267 | 0.230   | 0.436  | 0.340   | 0.001 |       |       |       |
| WORKING MEMORY          | -0.04  | 0.04   | 0.12   | 0.12   | 0.03   | -0.10 | 0.05  | -0.07 | -0.19   | -0.06  | 0.03    | 0.13  | 0.06  |       |       |
| SPENT SPAN (WM-DB)      | 0.782  | 0.705  | 0.363  | 0.329  | 0.089  | 0.422 | 0.686 | 0.348 | 0.313   | 0.590  | 0.774   | 0.270 | 0.604 |       |       |
| WORKING MEMORY          | 0.05   | 0.03   | -0.01  | 0.31b  | 0.32b  | 0.29a | 0.12  | 0.08  | 0.12    | 0.08   | -0.06   | 0.05  | 0.22  | 0.08  |       |
| WORD SPAN (WM-VE)       | 0.686  | 0.823  | 0.940  | 0.907  | 0.007  | 0.016 | 0.339 | 0.491 | 0.215   | 0.506  | 0.615   | 0.488 | 0.072 | 0.03  | 0.01  |
| WORKING MEMORY          | -0.08  | 0.06   | 0.05   | -0.15  | 0.09   | 0.01  | 0.01  | 0.03  | -0.04   | 0.11   | -0.20   | 0.25a | 0.32b | 0.03  | 0.01  |
| DOT SPAN (WM-DBS)       | 0.878  | 0.825  | 0.689  | 0.292  | 0.498  | 0.916 | 0.937 | 0.825 | 0.674   | 0.267  | 0.091   | 0.039 | 0.006 | 0.03  | 0.024 |

Key: a =  $p < 0.05$ ; b =  $p < 0.01$ ; c =  $p < 0.001$

TABLE 3

Pearson Product-Moment Correlations : Standard 5 Subjects

| CORRELATION COEFFICIENT | AGE    | RC     | VOC   | LC     | REG    | IRR    | MW     | MPGH   | MPKH-RRR | PSH   | PSM-BRR | WM-RS | WM-LB | WM-DB | WM-WB |
|-------------------------|--------|--------|-------|--------|--------|--------|--------|--------|----------|-------|---------|-------|-------|-------|-------|
| READABILITY             |        |        |       |        |        |        |        |        |          |       |         |       |       |       |       |
| READING                 | 0.01   |        |       |        |        |        |        |        |          |       |         |       |       |       |       |
| COMPREHENSION (RC)      | 0.992  |        |       |        |        |        |        |        |          |       |         |       |       |       |       |
| VOCABULARY (VOC)        | 0.02   | 0.45c  |       |        |        |        |        |        |          |       |         |       |       |       |       |
|                         | 0.978  | 0.001  |       |        |        |        |        |        |          |       |         |       |       |       |       |
| LISTENING               | -0.04  | 0.95c  | 0.39b |        |        |        |        |        |          |       |         |       |       |       |       |
| COMPREHENSION (LC)      | 0.782  | 0.001  | 0.003 |        |        |        |        |        |          |       |         |       |       |       |       |
| PSYCHOLOGY              | 0.76a  | 0.14   | 0.21  | 0.74   |        |        |        |        |          |       |         |       |       |       |       |
| REGULAR WORDS (REG)     | 0.090  | 0.284  | 0.110 | 0.398  |        |        |        |        |          |       |         |       |       |       |       |
| PSYCHOLOGY              | 0.78a  | 0.23   | 0.24  | 0.78a  | 0.86c  |        |        |        |          |       |         |       |       |       |       |
| REGULAR WORDS (IRM)     | 0.038  | 0.103  | 0.076 | 0.030  | 0.001  |        |        |        |          |       |         |       |       |       |       |
| PSYCHOLOGY              | 0.33a  | 0.09   | 0.15  | 0.22   | 0.84c  | 0.86c  |        |        |          |       |         |       |       |       |       |
| NONWORDS (NM)           | 0.014  | 0.482  | 0.162 | 0.100  | 0.001  |        |        |        |          |       |         |       |       |       |       |
| PSEUDOWORDS (PWS)       | -0.14  | 0.25   | -0.02 | 0.10   | -0.11  | 0.03   | -0.14  |        |          |       |         |       |       |       |       |
|                         | 0.314  | 0.062  | 0.057 | 0.669  | 0.418  | 0.046  | 0.293  |        |          |       |         |       |       |       |       |
| PSEUDOWORDS (PWS)       | 0.17   | -0.28a | -0.13 | -0.36b | -0.05  | -0.05  | -0.07  | -0.30a |          |       |         |       |       |       |       |
| WORDS (PWS-RR)          | 0.224  | 0.034  | 0.143 | 0.007  | 0.001  | 0.523  | 0.509  | 0.024  |          |       |         |       |       |       |       |
| PSEUDOWORDS (PWS)       | -0.16  | 0.28a  | 0.01  | -0.17  | -0.02  | 0.13   | -0.09  | 0.02c  | -0.39b   |       |         |       |       |       |       |
|                         | 0.222  | 0.032  | 0.059 | 0.207  | 0.009  | 0.339  | 0.486  | 0.001  | 0.002    |       |         |       |       |       |       |
| PSEUDOWORDS (PWS)       | -0.02  | -0.13  | -0.32 | -0.43c | -0.33a | -0.43c | -0.40b | 0.04   | 0.56c    | -0.27 |         |       |       |       |       |
| WORDS (PWS-RR)          | 0.808  | 0.330  | 0.016 | 0.001  | 0.011  | 0.001  | 0.002  | 0.751  | 0.001    | 0.369 |         |       |       |       |       |
| READING MEMORY          | -0.19  | 0.04   | 0.01  | -0.11  | -0.35b | -0.42b | -0.56c | 0.23   | -0.06    | 0.20a | 0.23    |       |       |       |       |
| READING SPAN (RS-RE)    | 0.166  | 0.789  | 0.276 | 0.399  | 0.008  | 0.002  | 0.001  | 0.095  | 0.652    | 0.026 | 0.101   |       |       |       |       |
| WORKING MEMORY          | -0.30a | 0.20   | 0.18  | 0.25   | -0.11  | -0.07  | -0.21  | 0.29a  | -0.33a   | 0.25  | -0.06   | 0.57c |       |       |       |
| LISTENING SPAN (WS-LR)  | 0.027  | 0.136  | 0.174 | 0.062  | 0.422  | 0.627  | 0.123  | 0.171  | 0.016    | 0.066 | 0.651   | 0.001 |       |       |       |
| WORKING MEMORY          | -0.02  | 0.18   | 0.13  | 0.24   | 0.10   | 0.13   | 0.12   | 0.14   | -0.12    | 0.24  | -0.26   | 0.01  | 0.07  |       |       |
| DECK SPAN (WS-DB)       | 0.308  | 0.174  | 0.181 | 0.069  | 0.454  | 0.363  | 0.369  | 0.139  | 0.388    | 0.066 | 0.055   | 0.932 | 0.594 |       |       |
| WORKING MEMORY          | -0.08  | 0.03   | 0.18  | 0.05   | -0.01  | -0.05  | -0.04  | -0.09  | -0.19    | -0.10 | -0.15   | 0.12  | 0.29a | 0.20  |       |
| WORD SPAN (WS-MS)       | 0.555  | 0.816  | 0.183 | 0.718  | 0.234  | 0.338  | 0.457  | 0.498  | 0.151    | 0.456 | 0.021   | 0.378 | 0.029 | 0.114 |       |
| WORKING MEMORY          | -0.29a | 0.08   | -0.04 | -0.12  | -0.41c | -0.43c | -0.55c | 0.31a  | -0.00    | 0.31a | 0.14    | 0.59c | 0.07c | 0.16  | 0.16  |
| DOT SPAN (WS-DOTS)      | 0.024  | 0.650  | 0.771 | 0.351  | 0.001  | 0.001  | 0.001  | 0.017  | 0.540    | 0.015 | 0.306   | 0.001 | 0.001 | 0.227 | 0.183 |

Key : a = p &lt; 0.05 ; b = p &lt; 0.01 ; c = p &lt; 0.001

3:  $r=.25$ ,  $p < .05$ ; Std 5:  $r=.59$ ,  $p < .001$ ), and with listening span for Std 3 and 5 subjects (Std 3:  $r=.32$ ,  $p < .01$  and Std 5:  $r=.52$ ,  $p < .001$ ). Dot counting span also correlated with digit span for Std 1 and 3 subjects (Std 1:  $r=.26$ ,  $p < .05$  and Std 3:  $r=.25$ ,  $p < .05$ ).

The results showed interesting differences in the patterns of significant correlations between standards with regard to the dependent variable, reading comprehension, and the mediating variables, namely listening comprehension, vocabulary and component reading skills. Reading comprehension correlated significantly with listening comprehension and vocabulary for all subjects as follows:

- i. Std 1 listening comprehension:  $r=.35$ ,  $p < .01$ ;  
vocabulary:  $r=.57$ ,  $p < .001$ .
- ii. Std 3 listening comprehension:  $r=.41$ ,  $p < .01$ ;  
vocabulary:  $r=.39$ ,  $p < .001$ .
- iii. Std 5 listening comprehension:  $r=.55$ ,  $p < .001$ ;  
vocabulary:  $r=.43$ ,  $p < .001$ .

Reading comprehension also correlated significantly with all the component reading variables for the Std 1 subject group. These were silent tests of phonology for regular ( $r=.60$ ,  $p < .001$ ), irregular ( $r=.50$ ,  $p < .001$ ), and nonword word-pairs ( $r=.62$ ,  $p < .001$ ) and lexical decision tests of the ability to reject nonwords (nonpseudohomophones:  $r=.51$ ,  $p < .001$ ; pseudohomophones:  $r=.51$ ,  $p < .001$ ). There was no relationship between reading comprehension and regular words and nonwords in the silent tests of phonology for Std 3 subjects. Both of these phonology tests tap the indirect nonlexical reading route. However, irregular words, which tap the direct or lexical reading route, correlated

significantly with reading comprehension ( $r=.32$ ,  $p < .01$ ) for these subjects. As with the Std 1 subjects, there was a significant correlation between reading comprehension and lexical decision tests of the ability to reject nonwords (nonpseudohomophones:  $r=.24$   $p < .05$ ; and pseudohomophones:  $r=.24$ ,  $p < .05$ ). The only component reading skill which correlated with reading comprehension for Std 5 subjects was the ability to reject pseudohomophonous nonwords ( $r=.29$ ,  $p < .05$ ). Incorrect acceptances of nonpseudohomophone (e.g. woap) and pseudohomophones (e.g. kee) in the lexical decision tests correlated negatively with reading comprehension for Std 1 ( $r = -.44$ ,  $p < .01$  and  $r = -.59$ ,  $p < .001$ , respectively) and Std 3 subjects ( $r = -.24$ ,  $p < .05$  and  $r = -.42$   $p < .01$ , respectively). Only incorrect acceptance of nonpseudohomophonous correlated negatively with reading comprehension for Std 5 subjects ( $r = -.29$ ,  $p < .05$ ).

Correlations for the combined group are shown in Table 10. There were interesting changes in correlation patterns, particularly between the working memory and reading tests and between the reading and language tests. Both simple and complex measures of working memory correlated with all tests of phonology and orthography with the exception of dot counting span and phonological discrimination of nonwords. Significant positive correlation coefficients ranged from .24 ( $p < .001$ ) for dot-counting results and discriminating between irregular word-pairs and .56 ( $p < .001$ ) between working memory listening span and lexical decisions of nonpseudohomophones. All of the working memory measures correlated with each other.

There was an absence of significant correlations between reading comprehension and tests of phonology



and orthography. However, the relationships between the HSRC tests, namely reading and listening comprehension, and vocabulary may not be meaningful as these tests differed from standard to standard. For example, the Std 5 tests were constructed and standardized for Std 5 pupils, and were more difficult than those constructed and standardized for Std 1 and 3 pupils. However, the tests of phonology, orthography and working memory were the same for all subjects and, therefore, significant correlations may well be meaningful. All the measures of phonology and orthography correlated significantly with one another and correlation coefficients ranged from .60 ( $p < .001$ ) to .91 ( $p < .001$ ). Significant negative correlation coefficients ranged from  $-.48$  ( $p < .001$ ) for nonword rhyming judgements and nonpseudo-homophone errors to  $-.65$  ( $p < .001$ ) for word/pseudohomophone discriminations and pseudohomophone errors.

There were significant positive correlations between age and most of the other variables ranging from .31 ( $p < .001$ ) to .73 ( $p < .001$ ). Exceptions included significant negative correlations with reading comprehension ( $r = -.23$ ,  $p < .001$ ) and listening comprehension ( $r = -.64$ ,  $p < .001$ ), although they may not be meaningful for these variables, as with nonpseudo-homophone errors ( $r = -.52$ ,  $p < .001$ ) and pseudohomophone errors ( $r = -.53$ ,  $p < .001$ ). The only variable that did not correlate with age was vocabulary ( $r = .09$ , ns). These results may indicate developmental trends in terms of age, possibly in addition to level of education. To test this possibility, the effects of age were partialled out and repeat correlation analyses were performed (see Table 11). In these analyses, the variables based on standardized HSRC test scores were excluded as these tests were not equivalent between standards.

TABLE 10

Pearson Product-Moment Correlations - Standard 1, 3 and 4 Subjects Combined

| CORRELATION COEFFICIENT  | AGE    | MC     | VOC    | LC     | REG    | IRN    | WH     | MPH    | MPH-ERR | PM     | PM-ERR | WR-RS | WR-LS | WR-DS | WR-WS |
|--------------------------|--------|--------|--------|--------|--------|--------|--------|--------|---------|--------|--------|-------|-------|-------|-------|
| PROBABILITY              |        |        |        |        |        |        |        |        |         |        |        |       |       |       |       |
| READING                  | -0.73c |        |        |        |        |        |        |        |         |        |        |       |       |       |       |
| COMPREHENSION (RC)       | 0.001  |        |        |        |        |        |        |        |         |        |        |       |       |       |       |
| VOCABULARY (VOC)         | 0.09   | 0.41c  |        |        |        |        |        |        |         |        |        |       |       |       |       |
|                          | 0.231  | 0.001  |        |        |        |        |        |        |         |        |        |       |       |       |       |
| LITERATURE               | -0.54c | 0.47c  | 0.19b  |        |        |        |        |        |         |        |        |       |       |       |       |
| COMPREHENSION (LC)       | 0.001  | 0.001  | 0.007  |        |        |        |        |        |         |        |        |       |       |       |       |
| PHONOLOGY                | 0.75c  | -0.42  | 0.18a  | -0.32c |        |        |        |        |         |        |        |       |       |       |       |
| REGULAR WORDS (REG)      | 0.001  | 0.221  | 0.012  | 0.001  |        |        |        |        |         |        |        |       |       |       |       |
| PHONOLOGY                | 0.71c  | 0.03   | 0.16a  | -0.27c | 0.91c  |        |        |        |         |        |        |       |       |       |       |
| IRREGULAR WORDS (IRN)    | 0.001  | 0.692  | 0.022  | 0.001  | 0.001  |        |        |        |         |        |        |       |       |       |       |
| PHONOLOGY                | 0.68c  | 0.01   | 0.23b  | -0.25c | 0.87c  | 0.88c  |        |        |         |        |        |       |       |       |       |
| NONWORDS (WH)            | 0.001  | 0.914  | 0.002  | 0.001  | 0.001  | 0.001  |        |        |         |        |        |       |       |       |       |
| NONWORD-ERRORS (MPH)     | 0.73c  | -0.02  | 0.23   | -0.38c | 0.78c  | 0.77c  | 0.5c   |        |         |        |        |       |       |       |       |
| NONWORD-ERRORS (MPH-ERR) | 0.001  | 0.737  | 0.075  | 0.001  | 0.001  | 0.001  | 0.001  |        |         |        |        |       |       |       |       |
| NONWORD-ERRORS (MPH-ERR) | -0.52c | -0.10  | -0.20b | 0.22b  | -0.54c | -0.56c | -0.48c | -0.62c |         |        |        |       |       |       |       |
| NONWORD-ERRORS (MPH-ERR) | 0.001  | 0.157  | 0.007  | 0.003  | 0.001  | 0.001  | 0.001  | 0.001  |         |        |        |       |       |       |       |
| NONWORD-ERRORS (PM)      | 0.65c  | 0.02   | 0.24a  | -0.30c | 0.74c  | 0.73c  | 0.68c  | 0.91c  | -0.54c  |        |        |       |       |       |       |
| NONWORD-ERRORS (PM)      | 0.001  | 0.274  | 0.049  | 0.001  | 0.001  | 0.001  | 0.001  | 0.001  | 0.001   |        |        |       |       |       |       |
| NONWORD-ERRORS (WR)      | -0.54c | -0.16a | -0.28c | 0.16a  | -0.83c | -0.64c | -0.57c | -0.48c | 0.70c   | -0.65c |        |       |       |       |       |
| NONWORD-ERRORS (WR)      | 0.001  | 0.023  | 0.001  | 0.031  | 0.001  | 0.001  | 0.001  | 0.001  | 0.001   | 0.001  |        |       |       |       |       |
| READING MEMORY           | 0.59c  | -0.13  | 0.07   | -0.36c | 0.45c  | 0.41c  | 0.33c  | 0.55c  | -0.40c  | 0.56c  | -0.38c |       |       |       |       |
| READING SPAN (RW-RS)     | 0.001  | 0.135  | 0.37a  | 0.001  | 0.001  | 0.001  | 0.001  | 0.001  | 0.001   | 0.001  | 0.001  |       |       |       |       |
| READING MEMORY           | 0.57c  | -0.09  | 0.23a  | -0.39c | 0.82c  | 0.82c  | 0.64c  | 0.56c  | -0.35c  | 0.56c  | -0.43c | 0.76c |       |       |       |
| READING SPAN (RW-LS)     | 0.001  | 0.387  | 0.032  | 0.001  | 0.001  | 0.001  | 0.001  | 0.001  | 0.001   | 0.001  | 0.001  | 0.001 |       |       |       |
| READING MEMORY           | 0.48c  | -0.02  | 0.16a  | -0.18b | 0.46c  | 0.36c  | 0.39c  | 0.39c  | -0.34c  | 0.38c  | -0.35c | 0.35c | 0.34c |       |       |
| READING SPAN (RW-DOTS)   | 0.001  | 0.812  | 0.029  | 0.610  | 0.001  | 0.001  | 0.001  | 0.001  | 0.001   | 0.001  | 0.001  | 0.001 | 0.001 |       |       |
| READING MEMORY           | 0.43c  | -0.03  | 0.13   | -0.13  | 0.47c  | 0.40c  | 0.32c  | 0.38c  | -0.38c  | 0.38c  | -0.40c | 0.37c | 0.45c | 0.33c |       |
| WORD SPAN (WR-WS)        | 0.001  | 0.881  | 0.082  | 0.873  | 0.001  | 0.001  | 0.001  | 0.001  | 0.001   | 0.001  | 0.001  | 0.001 | 0.001 | 0.001 |       |
| READING MEMORY           | 0.31c  | -0.04  | 0.01   | -0.26c | 0.30c  | 0.24c  | 0.13   | 0.43c  | -0.24c  | 0.43c  | -0.33c | 0.53c | 0.53c | 0.36c | 0.27c |
| WORD SPAN (WR-DOTS)      | 0.001  | 0.375  | 0.898  | 0.001  | 0.001  | 0.001  | 0.001  | 0.001  | 0.001   | 0.001  | 0.001  | 0.001 | 0.001 | 0.001 | 0.001 |

Key: a =  $p < 0.05$ ; b =  $p < 0.01$ ; c =  $p < 0.001$

TABLE 11

Pearson Product-Moment Correlations : Standard 1, 3 and 5 Subjects combined

Effects of age partialled out on Component Reading Skills and Working Memory Tests

| CORRELATION COEFFICIENT | REG    | IPK    | NW     | NPSH   | PPSH-ERR | PSH    | PSH-ERR | NM-RE | NM-LS | NM-DS | NM-MS |
|-------------------------|--------|--------|--------|--------|----------|--------|---------|-------|-------|-------|-------|
| REGULARITY              |        |        |        |        |          |        |         |       |       |       |       |
| PHONOLOGY               |        |        |        |        |          |        |         |       |       |       |       |
| REGULAR WORDS (REG)     |        |        |        |        |          |        |         |       |       |       |       |
| PHONOLOGY               | 0.75c  |        |        |        |          |        |         |       |       |       |       |
| IRREGULAR WORDS (IRR)   |        |        |        |        |          |        |         |       |       |       |       |
| PHONOLOGY               | 0.73c  | 0.73c  |        |        |          |        |         |       |       |       |       |
| NONWORDS (NW)           |        |        |        |        |          |        |         |       |       |       |       |
| PHONOLOGY               | 0.691  | 0.691  |        |        |          |        |         |       |       |       |       |
| PSEUDOWORDS (PSE)       |        |        |        |        |          |        |         |       |       |       |       |
| PHONOLOGY               | 0.39c  | 0.71c  | 0.20a  |        |          |        |         |       |       |       |       |
| REGULARITY              | 0.691  | 0.11c  | 0.825  |        |          |        |         |       |       |       |       |
| PSEUDOWORDS (PSE)       |        |        |        |        |          |        |         |       |       |       |       |
| REGULARITY              | -0.34c | -0.12c | -0.19a | -0.41c |          |        |         |       |       |       |       |
| PSEUDOWORDS (PSE)       |        |        |        |        |          |        |         |       |       |       |       |
| REGULARITY              | 0.37c  | 0.00   | 0.17   | 0.78c  | -0.38c   |        |         |       |       |       |       |
| PHONOLOGY               | 0.601  | 0.571  | 0.654  | 0.681  | 0.601    |        |         |       |       |       |       |
| PSEUDOWORDS (PSE)       |        |        |        |        |          |        |         |       |       |       |       |
| PHONOLOGY               | -0.34c | -0.00  | -0.26b | -0.23b | 0.68c    | -0.37c |         |       |       |       |       |
| REGULARITY              | 0.601  | 0.601  | 0.601  | 0.601  | 0.601    | 0.601  |         |       |       |       |       |
| WORKING MEMORY          |        |        |        |        |          |        |         |       |       |       |       |
| READING SPAN (RM-RE)    | 0.06   | 0.01   | -0.16  | 0.32c  | -0.14    | 0.36c  | -0.06   |       |       |       |       |
| READING SPAN (RM-LS)    | 0.13   | 0.12   | -0.01  | 0.21a  | -0.06    | 0.28c  | -0.10   | 0.63c |       |       |       |
| READING SPAN (RM-DS)    | 0.142  | 0.200  | 0.176  | 0.021  | 0.525    | 0.002  | 0.291   | 0.001 |       |       |       |
| READING MEMORY          | 0.28b  | 0.17   | 0.24b  | 0.02   | -0.14    | 0.06   | -0.10   | 0.06  | 0.15  |       |       |
| DIGIT SPAN (DM-RE)      | 0.010  | 0.060  | 0.086  | 0.712  | 0.136    | 0.481  | 0.287   | 0.389 | 0.099 |       |       |
| READING MEMORY          | 0.24b  | 0.09   | 0.07   | 0.02   | -0.17    | 0.02   | -0.18c  | 0.21a | 0.27b | 0.19c |       |
| WORD SPAN (WM-RE)       | 0.010  | 0.190  | 0.465  | 0.558  | 0.064    | 0.749  | 0.047   | 0.022 | 0.002 | 0.022 |       |
| READING MEMORY          | 0.02   | -0.11  | -0.17b | 0.15a  | -0.12    | 0.25b  | -0.07   | 0.55c | 0.49c | 0.22a | 0.27b |
| DMT SPAN (DM-DS)        | 0.613  | 0.200  | 0.002  | 0.026  | 0.173    | 0.005  | 0.410   | 0.001 | 0.001 | 0.016 | 0.002 |

Key : a = p &lt; 0.05 ; b = p &lt; 0.01 ; c = p &lt; 0.001

Certain significant correlations between working memory and reading results appeared to be dependent on age. Once age was partialled out, several of the intercorrelations between working memory tests and component reading skills were no longer statistically significant (compare Table 10 with Table 11). Exceptions were reading and listening spans with word/nonpseudohomophone and word/pseudohomophone lexical decision results, digit and word spans with making regular word rhyming judgements, dot and word spans with making nonword rhyming judgements, and dots with word/nonpseudohomophone and word/pseudohomophone lexical decision results. Word span correlated negatively with pseudohomophone errors. Partialling out the effects of age on component reading skills did not alter the high intercorrelation patterns. It also had little effect on the working memory intercorrelations with the exception of digit span and the two complex working memory measures, reading and listening spans.

### 7.2.2 Regression Analyses

A series of regression analyses were performed to determine the relative contribution of working memory to component reading skills, and of the component reading skills to reading comprehension. The following questions were posed both within and between standards:

- i. Which of the working memory measures (independent variables) and component reading and language skills (mediating variables) best predicted reading comprehension (dependent variable).
- ii. Which of the working memory measures (independent variables) best predicted component reading skills (mediating variables).

iii. Which of the component reading and language skills (mediating variables) best predicted reading comprehension (dependent variable).

Comparisons between reading comprehension and the language skills (listening comprehension and vocabulary) and component reading skills (regular and irregular word and nonwords rhyming judgments; lexical access for words vs. nonwords), and between the language skills (listening comprehension and vocabulary) and component reading skills and working memory (complex reading and listening spans and simple digit, word and dot counting spans) within the standards showed developmental changes. The Std 1, 3 and 5 results are discussed below.

The ability to make regular rhyming judgements ( $F=26.35$ ,  $p < .001$ ), vocabulary ( $F=18.07$ ,  $p < .001$ ) and the ability to discriminate between words and pseudohomophones ( $F=10.62$ ,  $p < .01$ ) were significant predictors of reading comprehension in Std 1 subjects. Although working memory reading span correlated with reading comprehension for these subjects ( $r=.27$ ,  $p < .05$ ), entering reading span into the regression equation did not account for any significant variance.

An absence of pseudohomophonous nonword errors ( $F=13.67$ ,  $p < .001$ ) and listening comprehension ( $F=6.51$ ,  $p < .01$ ) predicted reading comprehension in the Std 3 subjects. In the Std 5 subjects, significant predictors included listening comprehension ( $F=20.23$ ,  $p < .001$ ), vocabulary ( $F=7.63$ ,  $p < .01$ ), the ability to distinguish between words and pseudohomophones ( $F=4.05$ ,  $p < .05$ ) and a lack of pseudohomophonous nonword errors ( $F=4.63$ ,  $p < .05$ ).

The effects of age were controlled during the analyses performed on the combined group. When all working memory and component reading skill variables were entered into the equation, the lack of pseudohomophone errors ( $F=14.03$ ,  $p < .001$ ) and the ability to make nonword rhyming judgements ( $F=5.79$ ,  $p < .05$ ) were the best predictors of reading comprehension. These variables gave the same results when reading comprehension was regressed against component skills. The regression analysis of complex and simple working memory and reading comprehension yielded no significant results. However, when component reading skills were regressed against these working memory skills, there were several significant results. Digit span was a significant predictor for tests of phonology coding (Regular words:  $F=4.74$ ,  $p < .05$ ; nonwords:  $F=13.85$ ,  $p < .001$ ). Word span was the best predictor of making regular word rhyming judgements ( $F=8.79$ ,  $p < .01$ ), and contributed towards a lack of pseudohomophone errors ( $F=.99$ ,  $p < .05$ ). Reading span was the best predictor of being able to discriminate between words and nonpseudohomophones and pseudohomophones ( $F=14.37$ ,  $p < .001$ ;  $F=18.36$ ,  $p < .001$ ).

### 7.3 SUMMARY OF RESULTS

The results will be summarized according to the hypotheses. These will be restated for the reader's convenience.

- i. There will be a significant relationship between performance on complex and traditional working memory span tests and tests of reading comprehension.

The working memory reading span test only correlated with reading comprehension in the Std 1 subjects. When

reading span was forced into a regression equation against reading comprehension, reading span failed to account for any significant variance. Thus, the complex working memory tests used in this study failed to predict reading comprehension in any of the subject groups. None of the traditional measures of working memory, namely the word, digit and dot counting span related to reading comprehension. Therefore, the above hypothesis could not be unequivocally accepted.

ii. There will be significant relationships between all tests of working memory involving symbolic coding and tests of component reading skills.

Reading and listening span correlated significantly with the following:

- distinguishing between words and nonwords (both nonpseudohomophones and pseudohomophones) for the combined group (with the effects of age partialled out). Reading span was a significant predictor in each case.

Word span correlated significantly with the following:

- regular word rhyming judgements in the Std 1 and 3 subjects;
- irregular word rhyming judgements in the Std 3 subjects;
- rejecting nonpseudohomophone errors in the Std 1 subjects;
- rejecting pseudohomophone errors in the Std 5 subjects and the combined group with effects of age partialled out.

Digit span correlated significantly with the following:

- regular word rhyming judgements in the combined group with effects of age partialled out;

- nonword rhyming judgements in the combined group with effects of age partialled out;

Dot counting span correlated significantly with the following:

- regular word rhyming judgements in the Std 5 subjects;
- irregular word rhyming judgements in the Std 5 subjects;
- nonword rhyming judgements in the Std 5 subjects and in the combined group with effects of age partialled out;
- distinguishing between words and nonwords (both nonpseudohomophones and pseudohomophones) in the Std 5 subjects and in the combined subject group with the effects of age partialled out.

Thus, all the working memory tests correlated with one or more measures of component reading skills. This hypothesis was accepted.

iii. There will be a significant relationship between listening comprehension, vocabulary and reading comprehension.

Vocabulary and listening comprehension correlated with reading comprehension in the Std 1, 3 and 5 subjects. Vocabulary was a significant predictor of reading comprehension in the Std 1 and 5 subjects, and listening comprehension, in the Std 3 and 5 subjects. This hypothesis was accepted.

iv. There will be significant relationships between component reading skills and reading comprehension.



- All measures of component reading skills correlated significantly with reading comprehension in the Std 1 subjects. Regular word rhyming judgements and the ability to reject pseudohomophone errors were significant predictors of reading comprehension in this group.
- In the Std 3 subjects, irregular rhyming judgements and all the lexical decision tests correlated significantly with reading comprehension. The ability to reject pseudohomophone errors was also a significant predictor of reading comprehension in this group.
- The ability to distinguish between words and pseudohomophones and to reject nonpseudohomophone errors correlated significantly with reading comprehension in the Std 5 subjects. The former ability and the ability to reject pseudohomophone errors were significant predictors of reading comprehension in this group. This hypothesis was accepted.

v. There will be a significant relationship between working memory, listening comprehension and vocabulary.

The working memory listening span correlated with listening comprehension in the Std 1 subjects. No other working memory results correlated with listening comprehension, and no working memory results correlated with vocabulary.

vi. There will be a significant relationship between traditional tests of working memory and the complex memory span tests.

There were significant intercorrelations between all these tests for the combined subject group with the effects of age partialled out. Word span correlated with listening span in the Std 5 subjects. In the Std 1, 3 and 5 subjects, dot counting span correlated significantly with reading span, in the Std 3 and 5 subjects, it correlated with listening span, and in Std 3 subjects, it correlated with digit span. This hypothesis was accepted.

vii. There will be developmental differences in working memory and reading tests.

The following significant developmental differences were found and this hypothesis was accepted:

- working memory span for target subjects and objects in the complex reading and listening span tests between the Std 1 and 3, and Std 1 and 5 subjects;
- sequential retention and recall of digits during the digit span test for all subjects;
- short-term retention and recall for words during the word span test between the Std 1 and 5, and Std 3 and 5 subjects;
- short-term sequential retention and recall for the number of dots in card sets during the dot counting span test between Std 1 and 3 and Std 1 and 5 subjects;
- making rhyming judgements - between all subject groups for regular and irregular words and nonwords;
- distinguishing words from nonpseudohomophonous and pseudohomophonous nonwords between all subject groups;
- rejecting nonpseudohomophonous and pseudohomophonous errors between all subject groups.

## CHAPTER 8 DISCUSSION

### 8.1 GENERAL OVERVIEW

This study aimed to investigate the role of working memory, using traditional and complex span tests, in reading comprehension and other component reading skills in children of various ages. Furthermore, the role played by component reading skills and language abilities, namely listening comprehension and vocabulary, in reading comprehension were assessed. This study was undertaken from a developmental perspective and all the data were analysed for developmental trends. The results are discussed and interpreted based on the models of working memory, reading comprehension and reading development presented in previous chapters. In the following discussion, the combined subject group's results are those where the effects of age were partialled out unless otherwise specified. Implications of the results are discussed followed by suggestions for future research. The results are then summarized and conclusions drawn.

### 8.2 DISCUSSION OF WORKING MEMORY RESULTS

#### 8.2.1 Working memory in Reading

- (a) Working Memory and Reading Comprehension
  - (i) Complex Working Memory Tests

With the exception of the Std 1 subjects, the complex measures of working memory, namely reading and listening spans, did not correlate significantly with, or predict, the dependent variable, reading

comprehension. When reading span was entered into the regression equation, it failed to account for any significant variance in the Std 1 subjects. Thus, the hypothesis that complex measures of working memory, as measured by the present versions of reading and listening span tests, would predict reading comprehension cannot be accepted unequivocally.

Previous research into the role of working memory in reading comprehension in adults and children found significant correlations between complex memory span tests and reading comprehension (Baddeley et al, 1985; Daneman & Carpenter, 1980; Dixon, LeFevre, & Twilley, 1988; Mason & Miller, 1983; Torgeson, Rashotte, & Greenstein, 1988). Working memory, as measured by these tests, was also a significant predictor of reading comprehension. The present study did not replicate these findings in all of the subject groups.

The complex working memory span tests were adapted from those used by Baddeley et al. (1985). They were aimed at tapping the high-level storage and processing functions of working memory similar to those required during reading comprehension. However, the results of this study suggest that the complex working memory span tests relate to lower-level processing and storage functions involved in lexical access in reading. According to the W. Kintsch and van Dijk (1978, 1983) model of reading comprehension, these lower-level processes contribute to microstructural processing functions, which may take place in the phonological loop of the Baddeley model of working memory (1986, 1990). This may explain why there was a relationship between these complex working memory span tests and reading comprehension in the younger, and not in the older, subject groups.

Firstly, the Std 1 subjects appeared to be in a transition phase between the phonological-recoding or alphabetic, and the orthographic, reading stages (Frith, 1985; Harris & Coltheart, 1986; Seymour & MacGregor, 1984). Their results suggest that they relied to a large extent on indirect/nonlexical, but also used direct/lexical, reading strategies. However, retrieving semantic representations of words from print via phonological coding and lexical access for the purpose of creating a coherent text base may not yet be an automatic process in these subjects. It seems likely, therefore, that they allocated considerable storage space to lower-level processing during reading comprehension and made limited use of high-level text processing. Consequently, the phonological loop would still play an important role in reading in these children at their phase of reading development. The Std 3 and 5 subjects, on the other hand, appeared to be in the orthographic reading stage (Frith, 1985; Harris & Coltheart, 1986; Seymour & MacGregor, 1984). Semantic access would be automatic in these children and, therefore, reading comprehension would tap storage and processing in the phonological loop to a lesser degree.

Secondly, judging from the mouth movements observed while testing the Std 1 subjects, they probably subvocalized (a function of the articulatory control process in the phonological loop) while reading both the comprehension test passages and the sentences in the reading span test. It is possible, therefore, that the reading span task reflected the way in which they read far more closely than it did the reading strategies used by the older children.

Lastly, it is possible that all the subjects approached the complex reading and listening span tests in the

same way as the traditional working memory tests, that is, by decoding, rehearsing and storing sequences of items. High-level or macrostructural processing, such as making inferences and generalizations, which are important for reading comprehension (Kintsch, W. & van Dijk, 1978, van Dijk and Kintsch, W., 1983), were not required. As macroprocessing of text develops with reading experience (Kintsch, E., 1989), the age-appropriate reading comprehension tests for the Std 3 and 5 subjects would require them to make more use of high-level processing. Therefore, the complex working memory span and reading comprehension tests probably measured different levels of cognitive processing in these subjects. This may account for the absence of correlations between these tests in the older children.

#### (ii) Traditional Working Memory Tests

None of the traditional measures of working memory, namely the word, digit and dot counting spans, correlated with reading comprehension. Word span, involving verbal memory coding (Talley, 1986) accredited to the phonological loop, failed to correlate with reading comprehension. This may be due to the hypothesis that reading comprehension also involves the storage and processing functions of the central executive in addition to the phonological loop.

The lack of significant relationships between traditional word span tests and reading comprehension concurs with the findings of Daneman and Carpenter (1980) in adult subjects. However, these results are contrary to those reported by La Pointe and Engle (1990), who found that their simple word span tests compared favourably with the complex working memory span tests in predicting reading comprehension. In

these studies (La Pointe & Engle, 1990), the word span tests were presented on computer monitors. In the present study and that of Daneman and Carpenter (1980), they were presented auditorily. These differences in the input modality (i.e., visual vs. auditory) may have introduced confounding variables that account for the discrepancy in the results. These variables probably include visual processing skills, which would have been required to decode the printed words in the word span tests and the printed text in reading comprehension tests in the La Pointe and Engle (1990) studies.

An absence of significant correlations between digit span and reading comprehension in the present study is in line with results of studies in children, where age, intelligence and attention span were controlled (Bowers, Steffy, & Swanson, 1986), and in adults (Dixon, LeFevre, & Twilley, 1988). Dot counting span also failed to correlate with reading comprehension. However, Baddeley et al. (1985) and Siegel and Ryan (1989) found that dot counting span correlated weakly with reading comprehension in adults and children respectively. Initially Baddeley et al. (1985) postulated that the dot counting span was a measure of a general central executive rather than a specific language processor. However, they conceded that, because articulatory suppression interfered with counting, the dot counting span might rely on the phonological loop and not the central executive. This concession concurs with the results of the present study, which suggest that the dot counting span relies on storage and processing occurring in the phonological loop.

(b) Working Memory and Component Reading Skills

(i) Complex Working Memory Tests

Both the reading and listening span tests correlated with, and in some cases predicted, certain component reading skills. Reading span correlated with all the silent tests of phonology (i.e., rhyming judgements of regular and irregular words and nonwords) in the Std 5 subjects, and with the ability to distinguish between words and pseudohomophonous nonwords in the Std 1 and Std 5 subjects. It also correlated with, and was a significant predictor of, the ability to distinguish between words and nonpseudohomophones and pseudohomophones in the combined subject group. Listening span correlated with the ability to distinguish between words and nonpseudohomophones in Std 5 subjects and between words and nonpseudohomophones and pseudohomophones in the combined subject group. It also correlated with the ability to reject nonpseudohomophonous errors in Std 5 subjects.

Thus, there appears to be some relationship between the processes involved the reading and listening span tests and lexical access for words in children. The latter includes speed of lexical access and word specific knowledge, both of which are necessary to differentiate between words and nonwords that sound or look like words, but that are spelt incorrectly. Significant relationships between the complex working memory listening and reading span tests and lexical decision tests were previously reported in adult subjects by Baddeley et al. (1985) and Dixon, LeFevre, and Twilley (1988) respectively). It is feasible that the explanation given by Baddeley et al. (1985) of a common component underlying these abilities, possibly information processing speed, is also applicable in the



present study.

In addition to this, it has been suggested that children, who are normal readers, "... derived and utilized phonological information when making lexical decisions" (Johnston, Rugg, & Scott, 1988, p. 116) and when reading for meaning. The question of prelexical phonological coding (Coltheart, Besner, Jonasson, & Davelaar, 1979) is discussed in greater detail in section 8.3.1. Nevertheless, it may also account for the relationship between reading span and the silent tests of phonology in the Std 5 subjects, as well as for the relationships between reading span and the lexical decision tests in the subjects as a whole.

#### (ii) Traditional Working Memory Tests

The traditional working memory span measures used in this study involved short-term storage of, and subvocal rehearsal or phonological coding to maintain, memory traces. Therefore, theoretically they tapped the phonological short-term store and articulatory control process in the phonological loop. It has been suggested that the phonological loop is also involved in reading and language microprocessing and storage (Baddeley, 1986; Baddeley, Vallar, & Wilson, 1987; Daneman, 1987; Ellis, 1990; Gathercole, 1990). However, the pattern of significant correlations obtained between the traditional working memory measures and reading and language tests varied depending on the age of the subject groups.

Word span correlated significantly with the silent tests of phonology for regular word-pairs in the Std 1 and Std 3 subjects, and for irregular word-pairs in the Std 3 subjects. Word span was also a significant

predictor of the ability to make regular and irregular word rhyming judgements in the Std 1 subjects, and regular word rhyming judgements for the group as a whole. These results appear to support the view of Talley (1986) that word span involves verbal (phonological) coding.

Previously, Dixon, LeFevre, and Twilley (1988) found no relationship between measures of word span and lexical decision in adults. However, in the present study, word span correlated negatively with, and predicted the ability to reject, nonpseudohomophone errors in Std 1 subjects. In other words, those children who made many nonpseudohomophone errors performed poorly on the word span test and vice versa. Word span also correlated significantly with the ability to reject pseudohomophone errors in Std 5 subjects and in the combined subject group, and significantly predicted this ability in the latter. These results raise the possibility of common components occurring in both word span and lexical decision tests, and may also involve prelexical versus lexical access to be discussed in section 8.3.1.

Word span correlated significantly with listening comprehension in the Std 3 subjects. A possible reason for this relationship may be that successful recall during word span entails forming associations with previously stored knowledge, for example, linking words that have something in common, in addition to rehearsal, chunking, processing and storage. However, the lack of similar correlations in the other subjects, especially the Std 5 group, cannot be explained.

Digit span also correlated with component reading skills. Firstly, it correlated significantly with all the silent tests of phonology, namely, regular and irregular word and nonword rhyming judgements in the

Std 5 subjects, and with regular word and nonword rhyming judgements in the combined group. Digit span was a significant predictor of nonword rhyming judgements in the Std 5 and the combined subject groups, and of regular word rhyming judgements in the latter. These results are in line with those reported by Bowers, Steffy and Tate (1988), who found a significant relationship between digit span and word attack or phonological reading strategies. These researchers postulated an interaction between aspects of the phonological short-term store measured by digit span and phonological coding. This may also explain the relationships between digit span and silent tests of phonology in the present study.

Secondly, digit span correlated significantly with lexical decision tests, involving the discrimination between words and nonpseudohomophonous and pseudohomophonous nonwords, in the Std 5 subjects. This may indicate a relationship between short-term store and information processing speed involved in both immediate sequential digit recall and lexical access. These results differed from those reported by Dixon, LeFevre, and Twilley (1988), who found no relationships between measures of digit span and lexical decision in adults. This contradiction is surprising as both subject groups should use lexical reading strategies, although the Std 5 readers may not be as experienced as the adult readers.

Dot counting span predicted and correlated significantly with regular and irregular word and nonword rhyming judgements in the Std 5 subjects, and nonword rhyming judgements in the combined group. It is possible, therefore, that dot counting involves similar articulatory control processes and short-term storage

as phonological coding and short-term store in word-reading in the older children. Dot counting span also predicted and correlated significantly with the ability to distinguish between words and nonpseudohomophonous and pseudohomophonous nonwords in the Std 5 subjects, and correlated significantly with this ability in the combined group. This may again indicate the presence of a common underlying component, possibly information processing speed.

### (c) Conclusions

In general, both complex and traditional working memory span measures correlated with component reading skills. The latter involve lower-level processing necessary for reading comprehension, which together with working memory test may involve the phonological loop. The pattern of these correlations differs between the subject groups, probably depending on the nature of the storage and processing functions they use to perform the memory and reading tasks.

#### 8.2.2 Working Memory in General

##### (a) Relationships between Complex and Traditional Working Memory Tests

There were significant intercorrelations between the traditional and complex working memory tests for the combined subject group. Thus the hypothesis that there would be significant relationships between the traditional and complex working memory measures was accepted.

Reading span correlated with listening span in all subject groups, as was the case in the Daneman and Carpenter (1980) study. They suggested that this

indicated a common comprehension factor. In this study, there were no significant correlations between these complex span tests and reading and listening comprehension in most of the subject groups and, therefore, a common comprehension factor appears unlikely. Instead, these tests appear to indicate common storage and processing functions occurring in the phonological loop.

Word span correlated with listening span within the Std 5 subjects. Both of these tests involved auditory input into the phonological loop and its subvocal rehearsal and short-term store. The lack of similar relationships in the Std 1 and 3 subjects cannot be explained. Digit span failed to correlate with any of the complex span tests. This may be due to differences in the symbolic processing used, namely, linguistic for the complex span tests and numerical for the digit span test.

In each subject group, the dot counting span correlated with either one or both of the complex spans. In the Std 1, 3 and 5 subjects, dot counting span correlated significantly with reading span, and in the Std 3 and 5 subjects, it correlated with listening span. Case, Kurland and Goldberg (1982) postulated that the dot counting span was a measure of simultaneous nonverbal/spatial storage and processing functions in working memory. Baddeley et al. (1986) hypothesized that these functions related to a general central executive. They also suggested that the language based reading and listening span tests may relate to either a general central executive or a separate language processor. However, the fact that their subjects counted, in other words, used a speech code, when performing the dot counting span, may invalidate their interpretation, and may account for the relationships

between the dot counting span and verbal working memory measures. The results of this study suggest that both the dot counting and the complex span tests utilize the storage and processing functions of the phonological loop.

(b) Relationships between Traditional Tests

Dot counting span correlated with digit span in both the Std 1 and Std 3 subjects. Both the digit and dot counting span tests involved the symbolic processing of number sequences and required subvocal articulation, rehearsal and short-term store. The lack of a similar relationship in the Std 5 subjects may indicate increased automaticity for arithmetical operations in the older children. However, this postulation cannot be confirmed using the present data. The numerical span tests correlated with the word span measure, hereby supporting the popular hypothesis that both are indicators of short-term memory span (Lezak, 1983), probably involving the phonological loop.

The results of this study suggest a relationship between phonological coding, information processing speed and symbolic serial learning tasks, namely, the digit, word and dot counting span tests. This raises the possibility that the same phonological strategies, probably involving coding, rehearsal and articulation in addition to short-term storage and item identification speed, used for processing and remembering the digit and word series are used for counting and remembering the dot sequences.

### 8.3 DISCUSSION OF READING AND LANGUAGE RESULTS

#### 8.3.1 Component Reading Skills in Reading Comprehension

The pattern of intercorrelations between reading comprehension, the dependent variable, and the component reading variables differed between standards according to reading competence. Thus, the hypothesis that component reading skills contribute to reading comprehension was accepted.

Reading comprehension correlated with all the silent tests of phonology in the Std 1 subject group. These included regular and irregular word and nonword rhyming judgements. The regular word and nonword rhyming tests tap the indirect reading route, and these results are in line with a model of the development of phonological skills in reading and spelling (Cataldo & Ellis, 1988). This model suggests that explicit phonological awareness, implying the use of an analytical sound decoding strategies, becomes "... an important contributor to reading" (p. 99, *ibid.*) during the second and third years of formal education. Using these strategies, children apply letter-sound correspondence rules when reading words and nonwords and map the resultant sound sequences to their pronunciation. The meaning of words, necessary for reading comprehension, is accessed from the lexicon via their pronunciation. Their ability to judge whether nonwords rhymed or not indicates their ability to generalize knowledge of letter-sound relationships (Gaskins, Downer, Anderson, Cunningham, Gaskins, & Schommer, 1988). The tests of irregular word rhyming judgements, on the other hand, tap the direct or lexical reading route and cannot be performed by applying letter-sound correspondence rules. Pronunciation and meaning of irregular words is

specific to their orthographic representations. The relationship between the irregular words and reading comprehension suggest that the Std 1 subjects used lexical reading strategies to read familiar, high frequency irregular words.

There were no significant relationships between reading comprehension and regular words and nonwords in the silent tests of phonology in Std 3 subjects. However, irregular words correlated significantly with reading comprehension for these subjects, indicating the relative importance of accessing phonology and meaning via the lexical reading route. None of the silent tests of phonology correlated with reading comprehension in the Std 5 pupils suggesting a reliance on orthographic rather than phonological reading strategies.

There were significant correlations between reading comprehension and lexical decision tests of words versus nonpseudohomophonous (visually similar) and pseudohomophonous (phonologically similar) nonwords in the Std 1 and 3 subjects and between lexical access for words versus pseudohomophones in the Std 5 subject group. Nonpseudohomophonous and pseudohomophonous errors in the lexical decision tests correlated negatively with reading comprehension for Std 1 and 3 subjects, which indicated that the more accomplished readers made fewer word reading errors in phonologically and visually similar nonwords. Only nonpseudohomophonous errors correlated negatively with reading comprehension for Std 5 subjects. All subject groups were more prone to making pseudohomophone than nonpseudohomophone errors as was found in 8- and 11-year-old disabled readers and their chronological- and reading-age controls (Johnston, Rugg, & Scott, 1988).



Theoretically, these lexical decision tests tap the direct or lexical reading route indicating the ability to recognize words and reject nonwords. However, Coltheart, Besner, Jonasson, and Davelaar (1979) suggested that both nonlexical or prelexical phonological encoding and lexical reading strategies operate in parallel during lexical decision tasks, and that "... whichever is the fastest on a particular trial is responsible for ... pronunciation on that trial" (p. 504). Therefore, the futile search for lexical entries of nonwords may be long enough for the slower phonological coding to become evident through the pseudohomophone effect. This effect makes it more difficult to distinguish between words and pseudohomophones than between words and nonpseudohomophones, and results in pseudohomophone than nonpseudohomophone errors.

### 8.3.2 Listening Comprehension and Vocabulary in Reading

The hypothesis pertaining to correlations between reading comprehension, vocabulary and listening comprehension was accepted as significant intercorrelations occurred in all groups. These findings accord with those reported in adult studies (Baddeley et al, 1985; Daneman & Carpenter, 1980; Jackson & McClelland, 1979) and suggest that semantic access at word level and the ability to process verbal discourse are important factors contributing to reading comprehension. The correlation coefficient when comparing reading with listening comprehension was .35 ( $p < .01$ ) in the Std 1 group compared with .41 and .55 in the Std 3 and 5 ( $p < .001$ ) groups. This suggests a lag in reading comprehension compared with listening comprehension in these novice readers, which is in

line with the views of Durrell and Hayes (1970).

#### 8.4 INTERGROUP DIFFERENCES

There are very significant developmental changes in performance on all the variables measured between standards suggesting a progressive and pervasive development of cognitive functions. This development involved reading, general language skills, numeracy, information processing and memory. Thus, the hypothesis regarding developmental differences in working memory and reading was accepted. Of particular interest were the correlation patterns and the factors that predicted reading in the regression analyses.

##### 8.4.1 Intergroup Differences in Working Memory

Significant developmental differences in working memory results occurred in both complex and traditional tests. Working memory span for target subjects and objects in the complex reading and listening span tests differed significantly between the Std 1 and 3, and Std 1 and 5 subjects. There were no significant differences between Std 3 and Std 5 subjects on these complex working memory tests. Differences between the reading and listening span tests within subject groups were also not significant. These results suggest significant cognitive working memory development for visually and auditorily presented sentence material between the junior (Std 1) and senior primary subjects (Std 3 and 5).

Sequential retention and recall of digits improved significantly in all subjects. Short-term retention and recall for words improved between the Std 1 and 5, and Std 3 and 5 subjects, and for the number of dots in

card sets, between Std 1 and 3 and Std 1 and 5 subjects. These results suggested that developmental increases in the working memory between the younger and older children depended on the nature of the material (i.e, words vs. numbers). Unlike the results reported by Cohen and Heath (1990), word span was greater than digit span in all subjects. This difference between word and digit span was statistically significant in the Std 3 and 5 subject groups. This has important implications for the phonological loop hypothesis and will be used later in 8.5.4.

In general, the complex and traditional working memory span test results improved with age. Theoretically, both these span tests utilize the articulatory control processes and the phonological short-term store of the phonological loop. Consequently, one may expect that both operational efficiency and short-term span contribute to working memory improvement with age. However, as neither operational processing speed nor span were controlled, the trade-off between the two factors cannot be determined for comparison with other research findings (e.g, Case, Kurland, & Goldberg, 1982, and Huttenlocher & Burke (1976).

#### 8.4.2 Intergroup Differences in Reading

Correlation results on the reading tests showed very interesting developmental patterns. According to the Harris and Coltheart (1986) model of reading development, the following results can be expected when comparing component reading skills with reading comprehension:

1. A high correlation with phonology, but weak correlations with orthography in Std 1 readers.

- ii. Some correlation with phonology, possibly with nonwords, but a positive correlation with orthography in Std 3 readers.
  
- iii. No correlation between phonology and strong correlations with orthography in the Std 5 readers.

These expected patterns were virtually replicated in this study. The reading comprehension results from Std subjects, who probably still relied to a large extent on the nonlexical route for reading (Morton & Scarborough, 1980), correlated significantly with all silent measures of phonological coding. There were no significant differences in this group's ability to judge whether regular words and nonwords rhymed or not. They had acquired certain lexical reading skills, enabling them to pronounce irregular words and, therefore, judge whether these words rhymed or not. However, there was no significant difference between the irregular and the regular and nonword tests of phonology. This suggests that speed and accuracy was similar for all three tasks. Nevertheless, they still made many more visual and, particularly, phonological lexical errors than the older children, mistaking words for nonwords and vice versa.

The only test of silent phonology that correlated with reading comprehension in the Std 3 readers was that of irregular words. Regular and irregular word-reading in these children, therefore, did not appear to tap phonological coding as their ability to judge whether regular and irregular words rhymed or not was significantly better than that for nonwords, which does tap phonological coding. Instead, it seems likely that phonology for words was accessed directly via the

lexical reading route. Phonology for nonwords, which can only be accessed via the slower nonlexical route, significantly reduced their performance speed on this test. They were better than the Std 1 subjects at discriminating between words and pseudohomophones and nonpseudohomophones. However, they also made more pseudohomophone than nonpseudohomophone errors suggesting prelexical phonological recoding for some of these nonwords.

Reading comprehension did not correlate at all with the silent tests of phonology in the Std 5 readers. However, it did correlate significantly with the ability to discriminate between pseudohomophones and words and to reject nonpseudohomophone errors in this group. This suggests that these children were in the orthographic (fluent) reading stage, and that they used the lexical route for reading (Coltheart, Davelaar, Jonasson & Besner, 1977). These results resemble those indicating that efficient lexical access correlated highly with fluent reading in adults (Jackson & McClelland, 1979). The Std 5 subjects were significantly better than the Std 3 and Std 1 subjects at making rhyming judgements for regular and irregular words and for nonwords, and at distinguishing between words and nonwords and rejecting pseudohomophone and nonpseudohomophone errors. Nevertheless, they still demonstrated a pseudohomophone effect by making more pseudohomophone than nonpseudohomophone errors. This again suggests prelexical phonological recoding for some of these nonwords.

Thus, there was a significant improvement in phonological and lexical processing and a concomitant decrease in word-reading errors with education and age. This suggests a progressive improvement in word-

specific lexical reading skills, enabling the direct identification of words and access to their pronunciation and meaning.

Results of a series of regression analyses to determine the relative contribution of working memory to component reading skills and comprehension, and of the component reading skills to reading comprehension showed similar developmental trends. In the Std 1 subjects, reading regular words, vocabulary and the ability to discriminate between words and pseudohomophones (words that sound like real words when applying letter-sound conversion strategies) were significant predictors of reading comprehension. In the Std 3 subjects, an improved word-specific knowledge, resulting in fewer pseudohomophone errors, and listening comprehension predicted reading comprehension. Significant predictors in the Std 5 subjects included listening comprehension, vocabulary, the ability to distinguish between words and pseudohomophones.

The significant relationship between reading and listening comprehension in older children raises the possibility that they also made more use of high-level macrostructural processing. Furthermore, semantic access for word meanings in the older children using lexical reading strategies would be more automatic, thereby freeing working memory storage space for high-level processing. However, memory storage capacity alone cannot differentiate reading comprehension competency. Speed and accuracy of lexical access and information processing efficiency in reading tasks are also necessary.

Thus, in general, many of the variables show age and/or level of education effects. Age appeared to be the single most important predictor of reading comprehension in the combined group.

## 8.5 IMPLICATIONS

### 8.5.1 Introduction

With the exception of the hypotheses involving the complex working memory skills and reading comprehension, all the hypotheses, based on the development of skills necessary for fluent reading, (i.e., phonological coding, lexical access, word knowledge, language processing and comprehension and memory), were accepted on the basis of the results. This has important implications in terms of the models on which this research was based as well as for understanding reading disabilities.

### 8.5.2 Working memory and its Role in Reading

#### (a) Phonological Loop and Reading

Phonological coding and auditory short-term store are interrelated and appear to play a vital role in oral and written language development (Gathercole & Baddeley, 1989, 1990). Phonological coding may also contribute towards working memory storage given that phonological codes are activated either indirectly by subvocal speech or articulation during visual, or directly during oral, presentations of verbal memory stimuli (Brady, 1986; Ellis & Large, 1987; Torgesen, Wagner, Simmons, & Laughon, 1990). Moreover, Ellis (1990) proposed that reading enhanced the growth of phonological and auditory short-term memory skills. These skills, in turn, then promoted the development of visual short-term memory for letters and words. In

addition, the phonological loop appears to be involved in the development of general language skills, including vocabulary and listening comprehension (Baddeley, Vallar, & Wilson, 1987; Gathercole & Baddeley, 1989), which are important contributors to reading comprehension.

According to the model of working memory (Baddeley, 1986, 1990), phonological coding and auditory short-term store occur in the phonological loop. The traditional working memory tests used in this study, namely, the digit, word and dot counting span tests, involved both these functions. These tests correlated significantly with some or all tests of phonological component reading skills in line with suggestions that the phonological loop may be involved in reading (Gathercole & Baddeley, 1989, 1990; Ellis, 1990). The implications of these statistically significant relationships are discussed below.

Firstly, regular word rhyming judgements were the primary predictor of reading comprehension in the Std 1 subjects, suggesting that the phonological loop plays an important role in early reading development. In this regard, it may be involved in deriving phonological representations of visually presented words and in storing them until judgements can be made as to whether they rhyme or not in silent tests of phonology (Baddeley, Vallar, & Wilson, 1987).

Secondly, there was evidence of phonological coding in the older subjects. The higher incidence of pseudo-homophone versus nonpseudohomophone errors in the older, as well as in the younger, children indicates that prelexical phonological coding occurred during the lexical decision tests. Therefore, the older children



appeared to resort to phonological word-reading strategies when unable to access a lexical entry for a particular word, and when reading nonwords.

Deficiencies in the phonological loop, therefore, may be implicated in language and reading disabilities. Firstly, a combination of both phonological coding (articulatory and acoustic) and working memory short-term store deficits, reported in reading disabled children (Siegel & Ryan, 1988), may inhibit the acquisition of direct and indirect reading skills (Brady, 1986; Ellis & Large, 1987; Torgesen, Wagner, Simmons, & Laughon, 1990). However, not all reading disabled children show decoding deficits. According to Aaron (1991), children with nonspecific reading disabilities have adequate decoding skills, but are poor at reading comprehension. Other important mediating variables for reading comprehension, besides phonological and orthographic coding skills, tested in the present study were vocabulary and listening comprehension. Therefore, deficits in these basic language skills (vocabulary and listening comprehension) may underlie comprehension deficits in children with nonspecific reading disabilities (Aaron, 1991).

Thus the phonological loop may contribute to phonological coding and the acquisition of grapheme to phoneme correspondence rules in young children. It also appears to play a role in the development of basic language skills, namely, vocabulary and listening comprehension, that contribute towards reading. Older, more fluent readers may also make use of the phonological loop for reading unfamiliar words and nonwords.

Daneman (1987) and Daneman and Tardif (1987) found that the mode in which memory material was processed (i.e., symbolic vs. spatial) was a crucial predictive factor connecting working memory to reading. The working memory and reading tests used in this study involved symbolic processing. The possibility that the relationships found in this study indicate a common symbolic processing factor, and that phonological loop may act as a symbolic or language processor, cannot be excluded. These are discussed in more detail in the following section.

#### (b) Central Executive and Reading

Fluent reading involves high-level text processing, which is usually attributed to the central executive. However, this was not measured directly by the complex working memory tests used in this study. Instead, it was inferred from the results obtained for other tests, namely, measures of listening comprehension. The complex reading and listening working memory span tests, devised to assess the storage and processing functions of the central executive, correlated with lower-level storage and processing functions usually attributed to the phonological loop. This may be due to the nature of the test material, as there were significant correlations between the complex and traditional working memory span tests. Macroprocessing as such was not required for competent performance.

The older subjects could, however, process and store more target cued arguments in the complex working memory span tests than younger ones. These results are in line with other findings that younger children devote more time to decoding at word-level and micro-structural processing, resulting in limited resources

for storage and attention to higher-level processing, such as comprehension (Hess & Radtke, 1981). However, the results may also implicate the mnemonic window in phonological short-term store in the the phonological loop postulated by Baddeley, Vallar, and Wilson (1987). The younger children had a smaller memory span, which would reduce the number of chunks that could be stored in the mnemonic window in order to understand discourse. This would have consequences for reading comprehension, as their text processing skills are not yet automatic, and this would limit the available storage space.

Listening comprehension entails similar high-level processing to reading comprehension, and the results of these tests correlated significantly for all age groups. These findings were in line with those reported by Baddeley et al. (1985) and Daneman and Blennerhassett (1984) in adults and children respectively. However, the relative importance of listening comprehension as a predictor of reading comprehension differed between the younger and older subject groups. Vocabulary and phonological coding, rather than listening comprehension, were significant predictors of reading comprehension in the Std 1 subject group. In terms of the development of macroprocessing in reading comprehension (E. Kintsch, 1989), this suggests that they were still concerned with processing text at word-level, rather than at a sentence- or paragraph-level. Due to immature fluent reading skills, much effort and working memory capacity would be allocated to lower-level processing. In addition to these factors, the Std 1 subjects have significantly smaller memory spans compared to the Std 3 and 5 subjects. Possible reasons for this will be discussed in 8.5.4. Therefore, in general,

comprehension in younger children may be restricted by limited operational efficiency and by the amount of available memory span capacity.

Listening comprehension was a significant predictor of reading comprehension in the Std 3 and Std 5 subject groups. This suggests an increase in use of macroprocesses, namely, making inferences and generalizations from discourse material to integrate with prior knowledge. These macroprocesses are "... a major distinguishing characteristic of skilled readers ..., which enable them to relate the ideas in a text one to another and to general knowledge" (Oakhill, 1984, p. 31). The increase in use of macroprocesses may coincide with firstly, the improved efficiency of lower-level reading strategies, such as, direct lexical access during reading, and secondly, the increased availability of attentional resources (Keenan & Brown, 1984) associated with the central executive. These results appear to support the hypothesis of the development of macroprocessing with age (E. Kintsch, 1989) in normal readers.

The results have important implications for reading disabled children. Given that children with specific reading disabilities have difficulty in applying lower-level reading strategies due to cognitive deficits in, for example, phonological coding, they would have limited resources available for comprehension. Furthermore, learning disabled children, who can decode words, but have working memory deficits, will struggle to retain processed propositions long enough to integrate them into a text base for higher-level processing (Mann, Cowin, & Schoenheimer, 1989; Oakhill & Yuill, 1986). Children with nonspecific reading disabilities due to an underlying language deficiency

will also have difficulty with reading comprehension.

The relative contribution made by macroprocesses, usually attributed to the central executive, increases with age in normal readers. Deficits in reading comprehension in nonspecific reading disabilities have been associated with deficiencies in a general central executive (Swanson, Cochran, & Ewers, 1989; Yuill, Oakhill, & Parkington, 1989). However, there is mounting evidence for two separate processors, namely, verbal/symbolic and spatial, in working memory (Baddeley et al., 1985; Daneman, 1987; Daneman & Tardif, 1987; Waters, Caplan, & Hildebrandt, 1987). Daneman (1987) and Daneman and Tardif (1987) have postulated that these processors may be incorporated in the two working memory slave systems, namely, the phonological loop and visual-spatial sketch pad. Although differences in symbolic and spatial processing were not investigated in this study, the results suggest that the phonological loop is involved in both linguistic and numerical symbolic processing, both of which are symbolic. These findings may accord with the hypothesis of a symbolic processor. Further research comparing symbolic and spatial processing in reading development in normal children is necessary to investigate this postulation.

### 8.5.3 Reading Development according to the Dual-Route and Reading Stage Models

The relative importance of phonological and lexical reading strategies in the subjects dovetailed with the dual-processing models of reading acquisition (Coltheart & Harris, 1986). In general, children who were normal readers progressed from using phonological to using orthographic reading strategies.

In this study, the Std 1 children appeared to be in a transition phase between alphabetic (Frith, 1986; Seymour & MacGregor, 1984) or phonological-recoding (Harris & Coltheart, 1986), and the orthographic, reading stages. Although they used both indirect and direct reading strategies, phonological coding was still the most important predictor of reading comprehension in this group. They probably made use of the lexical reading route for a small number of words that they could recognize directly. However, at their stage of reading, many words are likely to be visually unfamiliar. They would, therefore, rely on phonological coding to read visually unfamiliar words and access their meanings from the semantic lexicon for reading comprehension purposes (Daneman, 1987; McCusker, Hillinger & Bias, 1981).

Although they were more proficient at phonological coding than the younger children, the Std 3, and particularly the Std 5, subjects made greater use of lexical reading strategies for comprehension purposes. This suggests that they are in the orthographic stage of reading development (Frith, 1986; Harris & Coltheart, 1986; Seymour & MacGregor, 1984). Nevertheless, they still used phonological reading strategies for deciphering unfamiliar words and nonwords.

The dual-route/stage models of reading development were formulated overseas (Frith, 1986; Harris & Coltheart, 1986; Seymour & MacGregor, 1984). From the results of this study, it seems likely that these models can be generalized to normal readers attending Transvaal Education Schools.

#### 8.5.4 Working Memory Development

Working memory capacity appears to increase significantly with age. Baddeley (1986) explained working memory development in terms of the central executive and the phonological loop. With regard to the latter, there was an improvement in rate of articulation or subvocalization associated with speech development and an increasing use of covert speech or rehearsal with age to aid memorization (Conrad, 1971; Ornstein, Naus, & Liberty, 1975; Torgeson & Goldman, 1977). The active rehearsal strategies used by older children allowed them to combine or chunk more memory items together (Kunzinger, 1985; Ornstein, Naus, & Liberty, 1975), thereby increasing their rehearsal set sizes (primacy effect) as well as working memory functional capacity. However, Cohen and Heath (1990) postulated that the number of both primacy (articulated) and recency (unarticulated) items recalled in memory tasks increased with age. They concluded that both the articulatory control process and the phonological short-term store in the phonological loop developed and could be responsible for individual differences in memory performance in children and adults.

All the memory span tests used in the present study required subvocal rehearsal to refresh the auditory or visual memory traces, as well as a passive form of short-term store. Thus, the superior performance in the older subjects could imply that they were better able to rehearse and store more memory items than the younger subjects. This would increase the chunk size of the mnemonic window (Baddeley, Vallar, & Wilson, 1987), thereby facilitating reading and listening comprehension.

In addition to this, speed of item identification and automatization, such as lexical access, and phonological coding skills may also be involved, as was advocated by Huttenlocher and Burke (1976), Lorschach and Gray (1986), Spring (1976), and Spring and Capps (1974). When considering these processing functions, there could be a trade-off between storage and processing in the younger subjects. However, these were not directly tested in this study.

Again, the developmental findings have implications for information processing tasks requiring working memory, such as reading, reasoning and mental arithmetic, in learning disabled children. Many of these children demonstrate slow item identification speeds (Lorschach & Gray, 1986), poor phonological coding and memory strategies (Brady, Mann, Schmidt, 1987). Cohen and Heath (1990) postulated that slow articulators take longer to process primacy items, and this reduces the amount of attention they can focus on recency items. However, the results of studies investigating the relationship between rate of articulation and reading are contradictory. Hulme, Thompson, Muir, and Lawrence (1984) found a positive relationship between articulation speed and reading, whereas Stanovich, Nathan, and Zolman (1988) did not. Nevertheless, learning disabled children are likely to perform below age-expectations on these tasks due to negative trade-off effects between processing and storage.

#### 8.5.5 Other Factors affecting Reading Comprehension.

Apart from the memory and component reading skills discussed above, there are other skills which contribute to reading comprehension, but which could not be tested directly in this study. Oral reading tests



of words and stories, and tests of visual reading strategies and iconic memory, which can only be done individually, were not considered. Other relevant reading skills that were not tested directly, due to the unavailability of suitable test material, included making inferences from, and detecting inconsistencies in, text.

Given that reading is an interactive cognitive process (Chase & Tallal, 1990; Walker, 1989; Weisberg, 1988), combining all the above mentioned skills. It was hoped that individual differences in the skills that were not tested would be minimized in the present study, as all the subjects were normal readers. However, the possibility that some of these skills were interfering variables cannot be excluded. These variables may add important information to future research into the role of working memory in reading development.

#### 8.6 FURTHER PROPOSED RESEARCH

This study has yielded interesting findings concerning the role of working memory in component reading skills. However, the author feels that the complex measures of working memory were not satisfactory in terms of the lack of significant results between them and measures of reading comprehension. Firstly, they did not appear to tap the macrostructural processes involved in reading comprehension, and instead, tapped lower-level processes and storage. Secondly, although the number of arguments to be processed increased with each series in the reading and listening span tests, syntactical difficulty was not manipulated, and no inferential judgements or text integration were required for competent performance. Future research could address these issues by constructing a range of working memory

tests involving a variety of processing and storage functions.

All the simple working memory span tests used in this study required symbolic processing, and therefore the Daneman (1987) and Daneman and Tardif (1987) postulation that there may be a spatial processor as well as a verbal/symbolic processor could not be examined. Future research could include both spatial and symbolic test in the battery to assess this postulate.

Although there may have been a trade-off between working memory storage and processing functions in the younger subjects in this study, the differences between these functions could not be measured using the present materials and procedures. Tests to examine the possible trade-off between processing and storage, similar to those used by Daneman (1987) and Daneman and Tardif (1987), could be included in future research.

## 8.7 OVERALL SUMMARY AND CONCLUSIONS

This study examined the interaction between component working memory functions and reading strategies and reading comprehension from a developmental perspective by modifying the study by Baddeley, Logie, Nimmo-Smith, and Brerston (1985). The subjects included children at various stages of reading development.

Most of the hypotheses tested in this study were accepted. The major findings were the following. Firstly, complex working memory span, measured by the reading and listening span tests, correlated significantly with reading and listening comprehension only in the younger subjects. Secondly, the complex

memory span tests correlated significantly with tests of component reading skills in the combined subject group (lexical reading strategies) and the Std 5 subjects (phonological and lexical reading strategies). Thirdly, traditional working memory span tests, including the word, digit and dot counting span tests, which correlated significantly with the complex working memory tests, also correlated with tests of phonological and lexical component reading skills. Lastly, the tests of component reading skills correlated significantly with reading comprehension. The patterns of these results reflected both reading and working memory development. These developmental results appeared to tie in with models of working memory and reading development. This suggests that these models could be used to understand working memory and reading development in normal and reading/learning disabled English-speaking pupils in Transvaal Education Department Schools.

The results suggest three major conclusions. The first is that reading is an interactive process and cannot be encapsulated by a single test. Therefore, a multi-test approach should be used for reading assessment and should be appropriate to the child's stage of reading development. Reading assessments should include tests of auditory and visual perception, phonological and lexical component reading strategies, visual and auditory vocabulary and memory and various aspects listening and reading comprehension.

The second conclusion involves the silent tests of phonology and the lexical decision tests. These tests of component reading skills are significant predictors of reading comprehension. They are easy to administer, and could be used to timeously identify children with

phonological or orthographic coding deficits. Testing could be done either individually or in a group situation, using age-related norms obtained from this study.

The final conclusion concerns the validity of the complex working memory span tests designed to tap central executive processing and storage functions in reading comprehension. A wider variety of these tests could be used in future reading research, with particular attention given to central executive versus phonological loop functions. In general, the central executive remains a vague construct requiring further research. This might help to clarify the role played by the central executive in reading comprehension. Moreover, the suggestion that there may be separate symbolic and spatial processors incorporated in the slave systems instead of a central executive require further investigation. A symbolic processor in the phonological loop would have far-reaching consequences for research into the role of working memory in reading.

**Appendix A**

**Silent Tests of Phonology: Practice Lists for Regular Homophones**

**TESTS OF PHONOLOGY**

NAME: \_\_\_\_\_

SEX: \_\_\_\_\_ STANDARD: \_\_\_\_\_

DATE OF BIRTH: \_\_\_\_\_

AGE: \_\_\_\_\_ YEARS \_\_\_\_\_ MONTHS

**INSTRUCTIONS**

On each line are two words. Sometimes the two words sound the same and sometimes they do not sound the same. If you think they SOUND the same put a tick in the SOUND SAME column. If you think they SOUND different put a tick in the DO NOT SOUND SAME column.

**PRACTICE LIST:  
REGULAR HOMOPHONES**

|      |      | SOUND<br>SAME | DO NOT<br>SOUND<br>SAME |
|------|------|---------------|-------------------------|
| pain | pant |               |                         |
| loan | long |               |                         |
| sail | sale |               |                         |
| loan | lone |               |                         |
| sail | salt |               |                         |
| pain | pane |               |                         |

**PRACTICE LIST  
REGULAR HOMOPHONES**

|      |      | SOUND<br>SAME | DO NOT<br>SOUND<br>SAME |
|------|------|---------------|-------------------------|
| nine | none |               |                         |
| boat | boot |               |                         |
| sea  | see  |               |                         |
| bear | beat |               |                         |
| tyra | tire |               |                         |
| bear | bare |               |                         |
| none | noon |               |                         |
| soot | suit |               |                         |
| mean | main |               |                         |
| sun  | son  |               |                         |

END OF PRACTICE TASK.

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Appendix B

Silent Tests of Phonology: Test Lists 1 and 2 for Regular Homophones

REGULAR HOMOPHONES: LIST 1

|        |       | SOUND<br>SAME | DO NOT<br>SOUND<br>SAME |
|--------|-------|---------------|-------------------------|
| rise   | rose  |               |                         |
| talks  | tax   |               |                         |
| passed | past  |               |                         |
| tail   | talk  |               |                         |
| put    | putt  |               |                         |
| tide   | tied  |               |                         |
| hair   | hare  |               |                         |
| made   | maid  |               |                         |
| hole   | whole |               |                         |
| meat   | melt  |               |                         |
| here   | hair  |               |                         |
| flee   | fled  |               |                         |
| hare   | hear  |               |                         |
| try    | tried |               |                         |
| praise | plays |               |                         |
| here   | hear  |               |                         |
| plain  | plant |               |                         |
| nissed | mast  |               |                         |
| paced  | paste |               |                         |
| gone   | gown  |               |                         |

REGULAR HOMOPHONES: LIST 2

|        |        | SOUND<br>SAME | DO NOT<br>SOUND<br>SAME |
|--------|--------|---------------|-------------------------|
| tail   | tale   |               |                         |
| board  | bored  |               |                         |
| but    | butt   |               |                         |
| days   | daze   |               |                         |
| wade   | ward   |               |                         |
| breed  | board  |               |                         |
| which  | winch  |               |                         |
| throne | thrown |               |                         |
| pause  | paws   |               |                         |
| which  | witch  |               |                         |
| read   | reed   |               |                         |
| days   | dare   |               |                         |
| flea   | flee   |               |                         |
| plain  | plane  |               |                         |
| rose   | rows   |               |                         |
| meat   | meat   |               |                         |
| paged  | paste  |               |                         |
| fed    | feed   |               |                         |
| tacks  | tax    |               |                         |
| here   | where  |               |                         |

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Appendix C

Silent Tests of Phonology: Practice List and Test List  
1 for Nonword Homophones

INSTRUCTIONS

On each line are two non-words. Sometimes the two non-words sound the same and sometimes they do not sound the same. If you think they SOUND the same put a tick in the SOUND SAME column. If you think they SOUND different put a tick in the DO NOT SOUND SAME column.

PRACTICE LIST:

NON-WORD HOMOPHONES

|       |       | SOUND<br>SAME | DO NOT<br>SOUND<br>SAME |
|-------|-------|---------------|-------------------------|
| zill  | ziel  |               |                         |
| ald   | ard   |               |                         |
| quued | kweed |               |                         |
| aud   | awd   |               |                         |
| querd | sneed |               |                         |
| zall  | zaul  |               |                         |

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NON-WORD HOMOPHONES: LIST 1

|        |        | SOUND<br>SAME | DO NOT<br>SOUND<br>SAME |
|--------|--------|---------------|-------------------------|
| cobe   | koab   |               |                         |
| fyde   | prode  |               |                         |
| zolk   | zole   |               |                         |
| bauze  | baws   |               |                         |
| oaf    | eeps   |               |                         |
| rabe   | ralb   |               |                         |
| afe    | aif    |               |                         |
| nied   | wide   |               |                         |
| coim   | koym   |               |                         |
| nime   | nyme   |               |                         |
| fraw   | fren   |               |                         |
| knoed  | knod   |               |                         |
| afe    | auf    |               |                         |
| passed | possed |               |                         |
| knool  | nule   |               |                         |
| kern   | keam   |               |                         |
| bauze  | bams   |               |                         |
| scane  | skain  |               |                         |
| voiled | voled  |               |                         |
| oaf    | eeph   |               |                         |

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Appendix D

Silent Tests of Phonology: Test List 2 for Nonword Homophones and Practice List for Irregular Homophones

NON-WORD HOMOPHONES: LIST 2

|        |       | SOUND<br>SAME | DO NOT<br>SOUND<br>SAME |
|--------|-------|---------------|-------------------------|
| vight  | vite  |               |                         |
| myfe   | mife  |               |                         |
| dassed | dast  |               |                         |
| colm   | boym  |               |                         |
| zight  | zeet  |               |                         |
| faps   | brex  |               |                         |
| voared | vored |               |                         |
| rabe   | raib  |               |                         |
| feeks  | phex  |               |                         |
| fyde   | phide |               |                         |
| oobe   | roib  |               |                         |
| frew   | frue  |               |                         |
| keam   | keem  |               |                         |
| pirg   | purg  |               |                         |
| soang  | skain |               |                         |
| dyfe   | dufe  |               |                         |
| zole   | zoal  |               |                         |
| nime   | nume  |               |                         |
| parg   | prug  |               |                         |
| nied   | niek  |               |                         |

INSTRUCTIONS

On each line are two words. Sometimes the two words sound the same and sometimes they do not sound the same. If you think they SOUND the same put a tick in the SOUND SAME column. If you think they SOUND different put a tick in the DO NOT SOUND SAME column.

PRACTICE LIST:  
IRREGULAR HOMOPHONES

|      |      | SOUND<br>SAME | DO NOT<br>SOUND<br>SAME |
|------|------|---------------|-------------------------|
| oar  | oare |               |                         |
| ory  | quay |               |                         |
| none | nun  |               |                         |
| key  | quay |               |                         |
| bone | bun  |               |                         |
| war  | wore |               |                         |

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Appendix E

Silent Tests of Phonology: Test List 1 and 2 for Irregular Homophones

IRREGULAR HOMOPHONES: LIST 1

|         |        | SOUND<br>SAME | DO NOT<br>SOUND<br>SAME |
|---------|--------|---------------|-------------------------|
| known   | nose   |               |                         |
| bold    | boiled |               |                         |
| where   | were   |               |                         |
| earn    | urn    |               |                         |
| late    | light  |               |                         |
| hall    | hill   |               |                         |
| berry   | bury   |               |                         |
| right   | write  |               |                         |
| blew    | blue   |               |                         |
| know    | no     |               |                         |
| feet    | fete   |               |                         |
| while   | white  |               |                         |
| may     | my     |               |                         |
| through | three  |               |                         |
| ferry   | fury   |               |                         |
| barn    | urn    |               |                         |
| sew     | so     |               |                         |
| snake   | sneak  |               |                         |
| guise   | guilt  |               |                         |
| blow    | blew   |               |                         |

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IRREGULAR HOMOPHONES: LIST 2

|         |        | SOUND<br>SAME | DO NOT<br>SOUND<br>SAME |
|---------|--------|---------------|-------------------------|
| ate     | eight  |               |                         |
| peace   | piece  |               |                         |
| knot    | not    |               |                         |
| know    | no     |               |                         |
| grew    | glue   |               |                         |
| nice    | niece  |               |                         |
| stood   | should |               |                         |
| brake   | break  |               |                         |
| hall    | haul   |               |                         |
| wood    | would  |               |                         |
| bold    | bowled |               |                         |
| knots   | nose   |               |                         |
| buy     | by     |               |                         |
| guise   | guys   |               |                         |
| car     | care   |               |                         |
| wear    | where  |               |                         |
| knob    | no     |               |                         |
| fate    | fete   |               |                         |
| sew     | new    |               |                         |
| through | threw  |               |                         |

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Appendix F

Lexical Decision Tests: Practice List and Test List 1

LEXICAL DECISION TASK

NAME: \_\_\_\_\_

DATE OF BIRTH: \_\_\_\_\_

SEX: \_\_\_\_\_ STANDARD: \_\_\_\_\_

INSTRUCTIONS

Read each string of letters carefully. Decide if it is a REAL WORD or NOT A WORD. If it is a REAL WORD put a tick in the REAL WORD column. If it is NOT A WORD put a tick in the NOT A WORD column.

PRACTICE LIST

|       | <u>REAL WORD</u> | <u>NOT A WORD</u> |
|-------|------------------|-------------------|
| nife  |                  |                   |
| knife |                  |                   |
| blood |                  |                   |
| mune  |                  |                   |
| moon  |                  |                   |
| fabe  |                  |                   |
| mud   |                  |                   |
| bluk  |                  |                   |
| fune  |                  |                   |
| fail  |                  |                   |
| tunc  |                  |                   |
| wife  |                  |                   |
| fale  |                  |                   |
| blud  |                  |                   |
| male  |                  |                   |
| mife  |                  |                   |

STOP. DO NOT TURN OVER.

LIST 1

|        | <u>REAL WORD</u> | <u>NOT A WORD</u> |
|--------|------------------|-------------------|
| wole   |                  |                   |
| wum    |                  |                   |
| ree    |                  |                   |
| prun   |                  |                   |
| friend |                  |                   |
| wise   |                  |                   |
| prano  |                  |                   |
| box    |                  |                   |
| toys   |                  |                   |
| mise   |                  |                   |
| thow   |                  |                   |
| soap   |                  |                   |
| crumb  |                  |                   |
| brain  |                  |                   |
| oake   |                  |                   |
| fluo   |                  |                   |
| soaf   |                  |                   |
| sleep  |                  |                   |
| fight  |                  |                   |
| shirt  |                  |                   |
| haw    |                  |                   |
| ped    |                  |                   |
| tood   |                  |                   |
| core   |                  |                   |
| set    |                  |                   |

STOP. DO NOT TURN OVER YET.

Appendix G

Lexical Decision Tests: Test Lists 2 and 3

| LIST 2. | REAL WORD | NOT A WORD |
|---------|-----------|------------|
| tree    |           |            |
| pole    |           |            |
| sead    |           |            |
| gun     |           |            |
| fole    |           |            |
| sope    |           |            |
| rox     |           |            |
| leap    |           |            |
| kuke    |           |            |
| nose    |           |            |
| glew    |           |            |
| kee     |           |            |
| drum    |           |            |
| wot     |           |            |
| cum     |           |            |
| chew    |           |            |
| send    |           |            |
| goat    |           |            |
| sine    |           |            |
| hurt    |           |            |
| books   |           |            |
| hood    |           |            |
| koat    |           |            |
| shurt   |           |            |
| bed     |           |            |

STOP. DO NOT TURN OVER YET.

| LIST 3 | REAL WORD | NOT A WORD |
|--------|-----------|------------|
| sould  |           |            |
| slurt  |           |            |
| woap   |           |            |
| loat   |           |            |
| yocks  |           |            |
| gite   |           |            |
| sign   |           |            |
| tox    |           |            |
| zine   |           |            |
| key    |           |            |
| cleap  |           |            |
| shoe   |           |            |
| rocks  |           |            |
| what   |           |            |
| seed   |           |            |
| plew   |           |            |
| wose   |           |            |
| come   |           |            |
| hoise  |           |            |
| said   |           |            |
| frent  |           |            |
| coat   |           |            |
| pake   |           |            |
| foal   |           |            |
| toes   |           |            |

STOP. DO NOT TURN OVER YET.

Appendix H

Lexical Decision Tests: Test List 4

LIST 4.

|       | REAL WORD | NOT A WORD |
|-------|-----------|------------|
| taw   |           |            |
| nine  |           |            |
| fite  |           |            |
| frend |           |            |
| noise |           |            |
| shew  |           |            |
| rope  |           |            |
| size  |           |            |
| toise |           |            |
| brane |           |            |
| socks |           |            |
| flew  |           |            |
| taks  |           |            |
| seat  |           |            |
| crum  |           |            |
| wize  |           |            |
| fox   |           |            |
| bite  |           |            |
| sleep |           |            |
| sed   |           |            |
| law   |           |            |
| got   |           |            |
| tose  |           |            |
| lane  |           |            |
| ood   |           |            |

END OF TASK.

Appendix I

An example from the Std 1 Vocabulary Test

Choose the best answer in each case.

1 When a cupboard is bare, it is.....

- A dirty.                  B untidy.                  C broken.                  D empty.

2 When a person is miserable, he is.....

- A unhappy.                  B stingy.                  C angry.                  D funny.

3 When something melts it becomes.....

- A hot.                  B tough.                  C soft.                  D stiff.

4 A signal is a.....

- A flag.                  B seal.                  C sign.                  D mark.

5 A colt is a.....

- A young horse.                  B flash.                  C baby's bed.                  D garment.

6 When an answer is honest, it is.....

- A rude.                  B false.                  C true.                  D quick.

7 When something moves to and fro, it.....

- A swings.                  B bounces.                  C rolls.                  D turns.

## Appendix J

### An example from the Std 3 Vocabulary Test

Choose the best answer in each case.

4 When you put something on show, you.....it.

- A erect                  B display                  C frame                  D view                  E sell

5 Close the door as there is a......

- A drag.                  B cold.                  C pull.                  D draught.                  E draught.

6 You cannot pass if you.....your work.

- A neglect                  B protect                  C suspect                  D regret                  E accept

Choose the word which has the same meaning as the word underlined.

7 recommend

- A examine                  B remember                  C suggest                  D remain                  E cure

Choose the best answer in each case.

8 Our phone number is not in the telephone,....

- A dictionary.                  B directory.                  C library.                  D exchange.                  E guide.

9 Someone who appreciates something is.....

- A playful.                  B thoughtful,                  C hateful.                  D helpful.                  E grateful.

10 You shrug your.....

- A head.                  B arms.                  C fist.                  D shoulders.                  E legs.

## Appendix K

### An example from the Std 5 Vocabulary Test

WHICH WORD CAN BEST REPLACE THE WORD UNDERLINED?

4. He beckons his friend to come.  
A winks      B gestures      C shouts      D exclaims      E tricks
5. Those two are sworn foes.  
A friends      B enemies      C professionals      D workers      E lumberjacks
6. He was reluctant to do the dangerous job.  
A willing      B keen      C able      D unwilling      E undecided
7. Their appealing faces were ignored by him.  
A rejecting      B begging      C ignorant      D smiling      E fearful
8. I am not sure whether they are acquaintances.  
A spectators      B hunters      C strangers      D enemies      E friends
9. To have a companion on a trip makes it more interesting.  
A map      B vehicle      C rod      D rucksack      E comrade
10. A friendly letter is simply a form of conversation.  
A chatting      B buying      C writing      D calculating      E building
11. It is pleasant to recall some happy incidents of the past.  
A events      B dreams      C thoughts      D ideas      E plans
12. The tops of the pines were reflected in the water.  
A floating      B mirrored      C sinking      D fastened      E moored
13. The nurse told us many weird stories.  
A popular      B old      C boring      D interesting      E strange

Appendix L

Test Lists A and B from the Rey Auditory Verbal  
Learning Test

LIST A

- 1 drum
- 2 curtain
- 3 bell
- 4 coffee
- 5 school
- 6 parent
- 7 moon
- 8 garden
- 9 hat
- 10 farmer
- 11 nose
- 12 turkey
- 13 color
- 14 house
- 15 river

LIST B

- desk
- ranger
- bird
- shoe
- stove
- mountain
- glasses
- towel
- cloud
- boat
- lamb
- gun
- pencil
- church
- fish



## Appendix M

### An example from the Std 1 Reading Comprehension Test

There are several ways in which camels have adapted themselves to desert conditions. They have broad feet which enable them to walk through the sand with ease. They have long eyelashes to keep the sand out of their eyes during a sandstorm. Most important, however, is the fact that they can travel long distances without water because they store water in their bodies.

6 Camels walk through sand without trouble because of their.....

- |       |             |                 |           |
|-------|-------------|-----------------|-----------|
| A     | B           | C               | D         |
| hump. | broad feet. | long eyelashes. | strength. |

7 Camels can travel far without water because they.....

- |   |                |
|---|----------------|
| A | store water.   |
| B | seldom drink.  |
| C | walk slowly.   |
| D | need no water. |

8 "Desert conditions" means that there.....

- |   |                  |
|---|------------------|
| A | are no roads.    |
| B | is a cold wind.  |
| C | are rainstorms.  |
| D | is little water. |

9 Long lashes protect the eyes of camels against.....

- |   |                 |
|---|-----------------|
| A | thirst.         |
| B | wind.           |
| C | long distances. |
| D | sandstorms.     |

## Appendix N

### An example from the Std 3 Reading Comprehension Test

One fine morning, from their rocky ledges, the baboons saw two horses being led up to the steep. Presently the farmer and one of his sons came out, mounted and rode away. The baboons watched them disappear over a distant hill. The foolish young baboons were wild with delight, and talked and jabbered about the good time they were going to have in the orchard, and wondered whether the farmer's wife would be making jam that day. If so, they would wait till it was well under way before frightening her off and seizing it.

- 26 The farmer and one of his sons came out.....
- |              |       |             |           |         |
|--------------|-------|-------------|-----------|---------|
| A            | B     | C           | D         | E       |
| immediately. | soon. | much later. | secretly. | slowly. |
- 27 The young baboons planned to.....
- |   |                           |
|---|---------------------------|
| A | ride the farmer's horses. |
| B | look after the orchard.   |
| C | climb the distant hill.   |
| D | go wild with delight.     |
| E | grab the jam.             |
- 28 When baboons jabber, they.....
- |          |         |          |         |        |
|----------|---------|----------|---------|--------|
| A        | B       | C        | D       | E      |
| chatter. | shiver. | grumble. | giggle. | fight. |
- 29 What pleased the baboons so much?
- |   |                              |
|---|------------------------------|
| A | It was a fine morning.       |
| B | They were young and foolish. |
| C | The farmer was away.         |
| D | They were in the orchard.    |
| E | The farmer's wife made jam.  |

## Appendix O

### An example from the Std 5 Reading Comprehension Test

On the march the tribes fought against him, and harassed him and killed his men, until he was forced to send back to Chaka to beg for an addition to his force. But Chaka refused; those he had with him should suffice. Nongogo went on until he reached the spot and started to return with the stone. And on his return march, one day, he fought a big battle. At sunrise he found himself surrounded by a large force of the enemy. The Zulus stood shoulder to shoulder, formed a square and fought manfully. When the sun set, most of the enemy were dead, but Nongogo was left with only ten men whom he continued to exhort to die like sons of Chaka, to let their last resting place be the heaped up bodies of their foes. The enemy saw that they were all being killed by the Mazulu and it was clear that, even when the last Zulu was dead, probably not more than one of their own men would be surviving and that would profit them nothing. So they let them be and departed.

*Thomas Mofolo: Nongogo and Nuyamana*

18. Whom did Nongogo ask for more men? He asked ... for more men.
- |       |           |         |       |        |
|-------|-----------|---------|-------|--------|
| A     | B         | C       | D     | E      |
| Zulus | the enemy | friends | Chaka | nobody |
19. What had Nongogo and his men gone to fetch? They had gone to fetch a ...
- |        |        |         |            |      |
|--------|--------|---------|------------|------|
| A      | B      | C       | D          | E    |
| spear. | stone. | shield. | knobkerry. | man. |
20. During this battle the Zulus used the tactics of ...
- A. surrounding the enemy.
  - B. standing close together in square formation.
  - C. ambushing the enemy in difficult terrain.
  - D. attacking at sunset.
  - E. fighting from behind the heaped up bodies of their foes.
21. How did Nongogo encourage his men? He ...
- A. told them to be careful.
  - B. set the example by fighting in front.
  - C. asked them not to be cowards.
  - D. told them to die like sons of Chaka.
  - E. reminded them that they were Zulus.
22. Why did the enemy stop attacking Nongogo's men?
- A. Nongogo's force had received reinforcements.
  - B. Nongogo's men were moving too fast for them.
  - C. Nongogo and his men were killing too many of them.
  - D. The tiny force of Nongogo were hidden in the bush.
  - E. Nongogo and his men only marched by night.

## Appendix P

### An example from the Std 1 Listening Comprehension Test

#### LISTENING COMPREHENSION STD ONE

Listen to the story, then answer the questions by choosing the correct answer and drawing a circle around the letter above or next to the correct answer

#### PRACTICE

1. A flower  
B button  
C needle  
D ribbon

2. The baby was put into a ...  
A pram  
B cot  
C walnut  
D basket

3. The cot was made in the shape of a ...  
A ball  
B bath  
C walnut  
D basket

STOP. DO NOT TURN OVER UNTIL YOU ARE TOLD TO.

1. The cat waits ... the house  
A behind  
B in front of  
C next to  
D at the back of

2. Japanese ladies are clever at  
A picking cherries  
B growing tea  
C arranging flowers  
D building homes

3. The Japanese arrange flowers with...  
A bamboo  
B cherry blossoms  
C cherries  
D tea blossoms

4. Rice is grown...  
A on the hills  
B in the valleys  
C on the slopes  
D near the mountains

5. During an earthquake a house of parchment is...  
A solid  
B strong  
C safe  
D dangerous

6. Camels walk through sand without trouble because of their  
A hump  
B broad feet  
C long eyelashes  
D strength

7. Camels can travel far without water because they...  
A store water  
B seldom drink  
C walk slowly  
D need no water

8. "Desert conditions" means that there...  
A are no roads  
B is a cold wind  
C are rainstorms  
D is little water

Appendix Q

An example from the Std 3 Listening Comprehension Test

LISTENING COMPREHENSION  
STANDARD THREE

Listen to the story then answer the questions by choosing the correct answer from the five possible answers and marking its letter on your ANSWER SHEET.

DO NOT WRITE ON THIS QUESTION SHEET.

PRACTICE

1. The lioness was tied up....

- A next to the lawn.
- B on the terrace.
- C under a tree.
- D on the stoep.
- E behind the house.

2. Why was the lioness tied up?

- A Father was cross.
- B The dogs barked at her.
- C She had to be fed.
- D The servants were afraid of her.
- E She grew angry.

3. The lioness....the scent of horses.

- A enjoyed
- B loved
- C disliked
- D disobeyed
- E welcomed

STOP. DO NOT TURN OVER THE PAGE UNTIL YOU ARE TOLD TO.

PAGE 2.

4. At the top of hills he....

- A drove fast.
- B drove carefully.
- C drove dangerously.
- D became reckless.
- E took chances.

5. While following the convict Clive had to....

- A lessen speed.
- B take advantage.
- C drive carelessly.
- D take heed.
- E take chances.

6. The fastest racing drivers....

- A take part in the race.
- B chase the convict.
- C are a risk on the road.
- D are safe drivers on the roads.
- F prefer narrow lanes.

7. Why did Clive take risks at first?

- A was a racing driver.
- B there were many bicycles.
- C He was chasing a convict.
- D The road was narrow.
- E It was hilly country.

STOP. DO NOT TURN OVER.

## Appendix R

### An example from the Std 5 Listening Comprehension Test

#### LISTENING COMPREHENSION STD FIVE

Listen to the story, then answer the questions by choosing the correct answer and marking its letter on your ANSWER SHEET

DO NOT WRITE ON THE QUESTION SHEET

#### PRACTICE

1. The lion charged in the direction of the ...

- A horses
- B hunters
- C bush
- D shelter
- E noise

2. Who looked after the horses?

- A girl
- B old servant
- C dog
- D young boy
- E old man

2. How was the lion killed?

- A One of the hunters shot him
- B The boy shot him
- C He fell and broke his neck
- D He was killed by a spear
- E One of the servants clubbed him to death

STOP. DO NOT TURN OVER UNTIL YOU ARE TOLD TO.

#### PAGE 2

4. They did not act as they wanted to because they were afraid they would ...

- A sink the boat
- B be overturned
- C draw too much attention
- D upset the captain
- E frighten the fish away

5. What could they not do quickly without danger?

- A pull their legs up out of the water
- B row away as fast as they could
- C throw a fish to the shark
- D find out from which quarter the danger threatened
- E shoot the shark

6. Before they threw the fish, they clearly saw ... above the surface of the water.

- A a dead fish
- B the outlines of a boat
- C the white breast of a shark
- D a shark fin
- E a floating log

7. The shark differs from other fish because ...

- A it is much larger
- B it has two rows of terrible teeth
- C its mouth is not at the point of its head
- D it always turns over on its side
- E when it attacks, its white breast rises

8. The attackers had ... on their heads

- A beads
- B caps
- C skins
- D feathers
- E helmets

## Appendix S

### Working Memory Reading Span Test

#### WORKING MEMORY READING TEST

NAME

STD

#### EXAMPLES

- 1 The baby wrote the letter
- 2 The mother carries the pencil
- 3 The bear jumped the wall
- 4 The cat tied the shoe
- 5 The fish sailed the sea
- 6 The mouse watched the sun
- 7 The dog caught the ball
- 8 The man packed the box
- 9 The grocer sold the sweets
- 10 The teacher went to school
- 11 The monkey chased the tail
- 12 The doctor wore the coat
- 13 The ant ate the bread
- 14 The clown stirred the tea

#### TEST 1 (2 SENTENCES)

- 1 The child broke the toys
- 2 The maid spilt the cream
- 3 The boy jumped the wall
- 4 The monkey opened the lock
- 5 The worm told the time
- 6 The king spilt the sugar

#### TEST 2 (3 SENTENCES)

- 7 The girl ran the race
- 8 The mother cut the bread
- 9 The singer sang the song
- 10 The sailor sailed the boat
- 11 The man caught the bus
- 12 The frog did the sums
- 13 The lady drank the tea
- 14 The cow walked the spoon
- 15 The lion ate the meat

#### TEST 3 (4 SENTENCES)

- 16 The girl told a lie
- 17 The monkey ate the apple
- 18 The baker baked the cake
- 19 The boy opened the door
- 20 The cat caught the mouse
- 21 The beetle ate the rose
- 22 The tiger told the clock
- 23 The pupil kicked the ball
- 24 The lady picked the rose
- 25 The owl saw the eye
- 26 The ape ate the rock
- 27 The man washed the car

Appendix T

Additional Items on the Working Memory Reading Span Test

TEST 4 (5 SENTENCES)

- 28 The father blew his nose
- 29 The donkey hit the nail
- 30 The dog chased the ship
- 31 The cook made the food
- 32 The rat wore the pen
- 33 The maid washed the rag
- 34 The baboon peeled the broom
- 35 The lady made the skirt
- 36 The boy did the sum
- 37 The barber cut the cake
- 38 The cat climbed the tree
- 39 The monkey ate the banana
- 40 The father hit the hammer
- 41 The doctor bit the bag
- 42 The butcher sold the meat

TEST 5 (6 SENTENCES)

- 43 The lady washed her face
- 44 The nurse blew the rag
- 45 The farmer milked the cow
- 46 The child read the book
- 47 The sailor whistled the tune
- 48 The baby drank the milk

- 49 The teacher beat the drum
- 50 The mother sailed the sea
- 51 The buck drank the water
- 52 The banker saved the money
- 53 The cat chased the wool
- 54 The owl saw the tree
- 55 The farmer planted the grass
- 56 The fly opened the page
- 57 The mouse kissed the chair
- 58 The boy watched the movie
- 59 The fox chased the ball
- 60 The nurse lit the lamp

TEST 6 (7 SENTENCES)

- 61 The pilot wore the plane
- 62 The duck told a lie
- 63 The man hit the box
- 64 The flea wrote a note
- 65 The buck kicked the leg
- 66 The king broke the dish
- 67 The girl wore the cap
- 68 The snail ran the race
- 69 The bird swam the ball
- 70 The pig drank the water
- 71 The rat told a story
- 72 The bee ate the open
- 73 The father built the house
- 74 The lady read the book



Appendix U

Additional Items on the Working Memory Reading Span  
Test.

75 The bear scratched the tree

76 The puppy ate the nut

77 The tiger drank the tea

78 The bird built the nest

79 The hen laid the egg

80 The frog caught the fly

81 The bull swept the house

END OF TEST

## Appendix V

### Working Memory Listening Span Test

#### WORKING MEMORY LISTENING SPAN

NAME \_\_\_\_\_

STD \_\_\_\_\_

#### EXAMPLES

- 1 The bird built the nest
- 2 The policeman rides the horse
- 3 The goat walked the leg
- 4 The king spilt the cream
- 5 The buck ate the grass
- 6 The monkey wore the cap
- 7 The boy shed a tear
- 8 The lady washed her face
- 9 The teacher read the book
- 10 The owl kicked the sock
- 11 The ape ate the nut
- 12 The man sailed the ship
- 13 The father kicked the ball
- 14 The mouse stole the cheese

#### TEST 1 (2 SENTENCES)

- 1 The bull ate the grass
- 2 The father cut the lawn
- 3 The dog chewed the bone
- 4 The boy sailed the boat
- 5 The king sold the sweets
- 6 The bear sang the shoe

#### TEST 2 (3 SENTENCES)

- 7 The lady drove the car
- 8 The flea told the time
- 9 The bee made the honey
- 10 The hen went to school
- 11 The baker swept the broom
- 12 The cow chewed the cud
- 13 The man blew his nose
- 14 The pig sailed the boat
- 15 The rat walked the pole

#### TEST 3 (4 SENTENCES)

- 16 The cat climbed the tree
- 17 The bird sings the song
- 18 The fish swam the race
- 19 The farmer lost his hair
- 20 The horse jumped the gate
- 21 The cow ate the oats
- 22 The fox made the bed
- 23 The donkey kicked the door
- 24 The mouse dropped the cup
- 25 The dog caught the ball
- 26 The ant spilt the sugar
- 27 The worm opened the door

Appendix W

Additional Items on the Working Memory Listening Span Test

TEST 4 (5 SENTENCES)

- 28 The boy watched the movie
  - 29 The hen laid the egg
  - 30 The man flew the kite
  - 31 The kitten chased the wool
  - 32 The pig wrote the chair
  - 33 The baboon peeled the broom
  - 34 The teacher went to school
  - 35 The beetle ate the flower
  - 36 The baby chewed the bone
  - 37 The girl caught the bus
  - 38 The cat scratched the flea
  - 39 The boy wore the shirt
  - 40 The pilot flew the plane
  - 41 The fish walked the foot
  - 42 The lion tied the lace
- TEST 5 (6 SENTENCES)
- 43 The king wore the crown
  - 44 The butcher sold the meat
  - 45 The frog swam the race
  - 46 The bear scratched his nose
  - 47 The cat climbed the tree
  - 48 The flea drank the soup

- 49 The pig ate the bread
- 50 The doctor carried the bag
- 51 The frog stirred the pot
- 52 The nurse lit the lamp
- 53 The queen whistled the tune
- 54 The lady picked the rose
- 55 The girl wrote the pencil
- 56 The mother washed the sock
- 57 The worm told the rock
- 58 The ape ate the time
- 59 The man packed the box
- 60 The sailor drank the tea

TEST 6 (7 SENTENCES)

- 61 The child played the toys
- 62 The snail caught the train
- 63 The fly ran the race
- 64 The lion ate the cake
- 65 The king sang the song
- 66 The singer stuck the pin
- 67 The duck made the bed
- 68 The rat walked the road
- 69 The fox turned the key
- 70 The mouse hit the stick
- 71 The bull beat the drum
- 72 The banker built the house
- 73 The owl stirred the spoon
- 74 The father saved the money

Appendix X

Additional Items on the Working Memory Listening Span  
Test

- 75 The cook made the food
- 76 The pilot swept the house
- 77 The horse did the sum
- 78 The ant sang the shoe
- 79 The queen made the cake
- 80 The girl combed her hair
- 81 The monkey chased the bee

END OF TEST

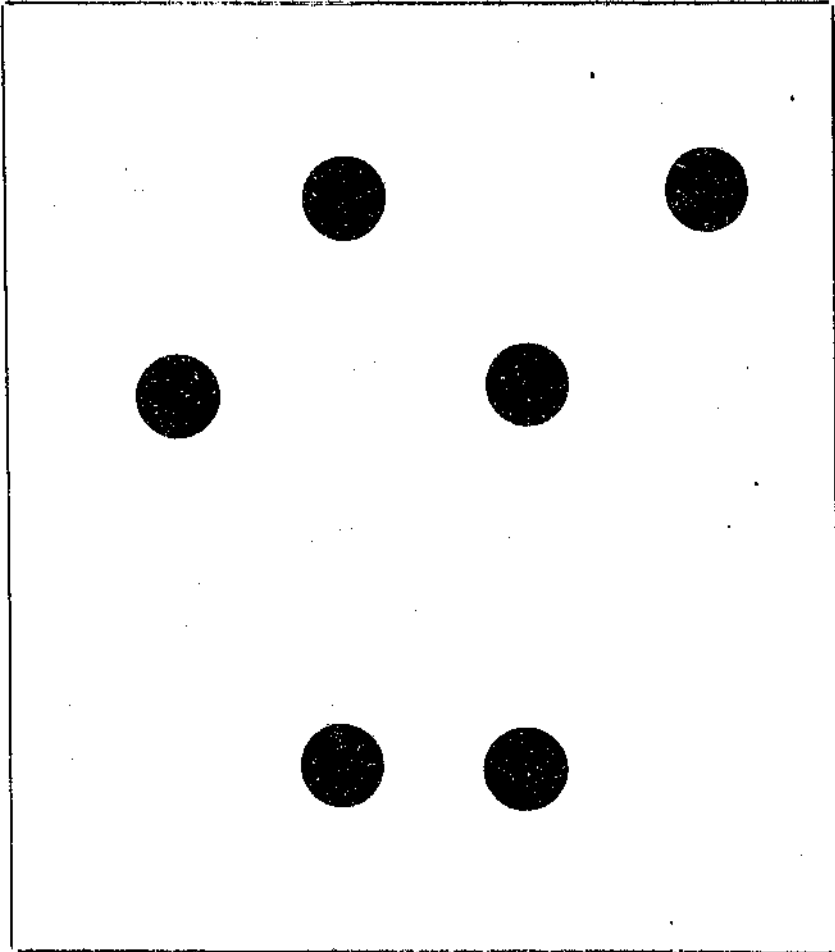
Appendix Y

Digit Span Subtest from the Wechsler Intelligence Scale  
for Children - Revised

| DIGITS FORWARD |                   | Pass-Fail | Trial 2           |           | Score<br>2, 1, or 0 |
|----------------|-------------------|-----------|-------------------|-----------|---------------------|
|                | Trial 1           |           |                   | Pass-Fail |                     |
| 1.             | 3-8-6             |           | 6-1-2             |           |                     |
| 2.             | 3-4-1-7           |           | 6-1-5-8           |           |                     |
| 3.             | 8-4-2-3-9         |           | 5-2-1-8-6         |           |                     |
| 4.             | 3-8-9-1-7-4       |           | 7-9-6-4-8-3       |           |                     |
| 5.             | 5-1-7-4-2-3-8     |           | 9-8-5-2-1-6-3     |           |                     |
| 6.             | 1-6-4-3-9-7-6-3   |           | 2-9-7-6-3-1-5-4   |           |                     |
| 7.             | 5-3-8-7-1-2-4-6-9 |           | 4-2-6-9-1-7-8-3-5 |           |                     |
| Total Forward  |                   |           |                   |           | Max.=14             |

Appendix Zi

An example of a Dot Counting Span Stimulus Card



**Appendix Zii**

**Dot Counting Span Answer Sheet**

**DOT COUNTING SPAN**

**INSTRUCTIONS:**

Count the number of GREEN DOTS on each card, and remember these totals. Write the totals down in the same order.

**EXAMPLE: One card set:**

\_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_

**Two card set:**

\_\_\_\_\_ \_\_\_\_\_  
\_\_\_\_\_ \_\_\_\_\_  
\_\_\_\_\_ \_\_\_\_\_

**Three card set:**

\_\_\_\_\_ \_\_\_\_\_ \_\_\_\_\_  
\_\_\_\_\_ \_\_\_\_\_ \_\_\_\_\_  
\_\_\_\_\_ \_\_\_\_\_ \_\_\_\_\_

**Four card set:**

\_\_\_\_\_ \_\_\_\_\_ \_\_\_\_\_ \_\_\_\_\_  
\_\_\_\_\_ \_\_\_\_\_ \_\_\_\_\_ \_\_\_\_\_  
\_\_\_\_\_ \_\_\_\_\_ \_\_\_\_\_ \_\_\_\_\_

**Five card set:**

\_\_\_\_\_ \_\_\_\_\_ \_\_\_\_\_ \_\_\_\_\_ \_\_\_\_\_  
\_\_\_\_\_ \_\_\_\_\_ \_\_\_\_\_ \_\_\_\_\_ \_\_\_\_\_  
\_\_\_\_\_ \_\_\_\_\_ \_\_\_\_\_ \_\_\_\_\_ \_\_\_\_\_

**Six card set:**

\_\_\_\_\_ \_\_\_\_\_ \_\_\_\_\_ \_\_\_\_\_ \_\_\_\_\_ \_\_\_\_\_  
\_\_\_\_\_ \_\_\_\_\_ \_\_\_\_\_ \_\_\_\_\_ \_\_\_\_\_ \_\_\_\_\_  
\_\_\_\_\_ \_\_\_\_\_ \_\_\_\_\_ \_\_\_\_\_ \_\_\_\_\_ \_\_\_\_\_

**Seven card set:**

\_\_\_\_\_ \_\_\_\_\_ \_\_\_\_\_ \_\_\_\_\_ \_\_\_\_\_ \_\_\_\_\_ \_\_\_\_\_  
\_\_\_\_\_ \_\_\_\_\_ \_\_\_\_\_ \_\_\_\_\_ \_\_\_\_\_ \_\_\_\_\_ \_\_\_\_\_  
\_\_\_\_\_ \_\_\_\_\_ \_\_\_\_\_ \_\_\_\_\_ \_\_\_\_\_ \_\_\_\_\_ \_\_\_\_\_

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