Verbal Learning, Phonological Processing and Reading Skills in Normal and Dyslexic Readers

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Abstract

This thesis reports a series of six experiments designed to study the development of verbal learning, phonological processing, and reading skills of normal reading (RA controls; CA controls) and dyslexic children. One aim of the research presented here was to investigate the relationship of verbal short term memory and reading skill in dyslexic and normal readers (RA controls; CA controls).

Experiments 1 and 2 investigate the memory span and speech rate skills of dyslexic and normal readers (RA controls; CA controls). The participants were administered lists of words and nonwords in a serial memory span task. Following this, a speech rate task was administered, in which the participants were asked to repeat item pairs as quickly and accurately as possible. The results of these experiments reveal that dyslexics are worse than their CA controls on memory span, but comparable to younger RA controls. Interestingly, no group differences were found in the quantitative analysis of the speech rate task. However, the speech rate error analysis revealed that dyslexics made more errors than normal readers.

Experiment 3 investigates the verbal learning abilities of dyslexic and normal readers (RA controls; CA controls). More specifically, the focus was on the ability of these children to learn visual-verbal paired associates. The result show that dyslexics learn fewer associations than RA and CA controls. Moreover, dyslexics make more errors overall than normal readers. Specifically, dyslexics make more extra-list errors than both RA and CA controls, whereas RA and CA controls make more intra-list errors.

Experiments 4 through 6 investigated the interrelationships of verbal short term memory, verbal learning, phonological awareness, and reading ability. The results suggest that normal reading children have two mechanisms in their reading systems: phonological awareness and verbal learning. Moreover, verbal learning is strongly associated with phonological awareness measures, and makes an independent contribution in the prediction of reading skill. In dyslexic readers, verbal learning is dissociated with phonological awareness, suggesting that the verbal learning mechanism may be less impaired. Plausibly, paired associate learning does not necessarily rely on phonological representations at the level required to set up mappings between phonemes and graphemes.

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Summary

The literature review in this thesis is presented in Chapters 1 and 2. Chapter 1 provides a detailed review of the phonological processing skills in normal reading children. More specifically, this review addresses the interrelationship among phonological awareness skills and reading ability from three methodological approaches: correlational studies, training studies, and longitudinal studies. Furthermore, the working memory literature is reviewed, primarily focusing on the developmental literature. Moreover, the working memory literature review addresses key issues such as the development of memory span and speech rate, and the relationship between verbal short term memory and reading skill.

Chapter 2 reviews the literature on developmental dyslexia. Indeed, there are several theories about the underlying causes of dyslexia. This chapter addresses three cognitive theories of dyslexia: the automatisation deficit, the visual deficit, and the verbal deficit. Primarily, this chapter focuses on dyslexia as a verbal deficit, or, as a core phonological deficit. Furthermore, this review addresses the relationship between phonological skills and reading, as well as verbal memory and reading in dyslexic children. Finally, this chapter reviews the literature on paired associate learning, which has typically been used as a measure of verbal long term memory. The paired associate learning literature in normal children is reviewed first, turning to a more extensive review on paired associate learning in dyslexic children.

Chapter 3 comprises two experimental studies, investigating the performance of dyslexics, reading age controls, and chronological age controls on tests of memory span and speech rate. Plausibly, dyslexic readers' deficiency in the ability to create phonological representations impairs phonological processing skills such as verbal

short term memory. The results show that there is a strong relationship between memory span and speech rate for dyslexics and normal readers. Thus, dyslexics and normal readers (RA controls; CA controls) are able to remember as much as they can articulate within a given time frame. Moreover, both dyslexics and normal readers (RA controls; CA controls) are sensitive to manipulations of length (short, medium, long) and lexicality (words, nonwords). Unexpectedly, group differences in the memory span and speech rate task were not found. However, a qualitative analysis of the speech rate errors suggests that the speech rate task provides an overestimation of the true speech rate of the dyslexic participants.

In Experiment 2, phonological neighbourhoods (high neighbourhoods, low neighbourhoods) were manipulated to provide a more sensitive index of the phonological deficit in dyslexic readers. Furthermore, the influence of morphological affixes on memory span was investigated to assess the contribution of semantic information to memory span. The results show that dyslexics verbal memory span is worse than chronological age controls, although comparable to younger RA controls. These results clarify the memory span results of Experiment 1, indicating that dyslexics do have poorer memory spans (Jorm, 1983). However, they also suggest that dyslexics are delayed, rather than deficient in their verbal short term memory processes. All three groups were sensitive to the phonological neighbourhood manipulations. Plausibly, the task is not sensitive enough to tap the quality of the phonological representation in the lexicon, because the task is not sufficiently difficult for the older dyslexics. Furthermore, dyslexics are less influenced by morphological information than normal readers, which suggests that dyslexics are poor at analysing items at both the phonological and morphological levels.

Chapter 4 is an investigation into dyslexic and normal reading children's (RA controls; CA controls) ability to learn visual-verbal paired associates. Plausibly, dyslexics did not show a deficit pattern in verbal short term memory tasks because the processes involved in verbal memory are not directly related to reading. Arguably, a task such as paired associate learning which is akin to reading, would show the expected deficit pattern. The results show that dyslexics are worse than both RA and CA controls on visual-verbal paired associate learning, supporting the hypothesis that tasks more directly relate to reading show greater deficits. Furthermore, these results suggest that dyslexics have difficulty in linking visual and verbal information.

In Chapter 5, the interrelationships between verbal leaning skills, verbal short term memory and phonological awareness in normal reading children ages 7-11 is investigated. The results of Chapter 4 suggest that verbal learning (as indexed by paired associate learning) is deficient in dyslexic readers. Therefore, it was necessary to establish the performance of normal reading children on this paired associate learning task. Moreover, we wanted to establish the relationship among measures of phonological awareness and verbal short term memory, and verbal learning to provide a comparison for subsequent research with dyslexic readers.

The results suggest that phonological awareness (phoneme deletion; rhyme oddity) and verbal learning (paired associate leaning) skills make independent contributions to the prediction of reading skill. Moreover, phonological awareness makes an independent contribution to the prediction of verbal learning skills. Third, verbal memory skills are poor predictors of reading ability, and do not make any contribution to verbal learning skills. It is suggested that paired associate learning and phonological awareness tasks tap separate mechanisms in the reading process. Plausibly, phonological awareness taps explicit knowledge of the phonological structure of words, and paired associate learning taps the ability to create connections between orthography and phonology. Both of these abilities are underpinned by the quality of underlying phonological representations, to a greater or lesser extent.

Chapter 6 is an investigation into the interrelationship among phonological processing skills (verbal short term memory, phonological awareness, speech rate), verbal learning (paired associate learning) and reading skill in dyslexic and normal readers (RA control, CA control). In line with the findings of Experiment 3, we expected to find a verbal deficit in the dyslexic readers compared to the normal readers (RA controls, CA controls). Moreover, we were interested in the relationship among these factors in dyslexic readers. In contrast to the results of Experiment 3, the results of Experiment 5 show that dyslexics are worse than CA controls on visual-verbal paired associates, but comparable to RA controls.

Interestingly, the relationship between phonological awareness (phoneme deletion; rhyme oddity) and verbal learning (paired associate learning) is different among dyslexics, than among normal readers. Paired associate learning is strongly associated with both measures of phonological awareness in normal readers, compared to a dissociation between these measures in dyslexics. Plausibly, there is more variation in paired associate learning ability because it does not necessarily rely on highly specified phonological representations. A dyslexic who has mildly impaired phonological representations, may be able to learn to associate the visual stimuli with larger word segments such as the syllable. Conversely, phonological awareness necessarily requires the ability to explicitly manipulate language at the level of the onset-rime, and the phoneme.

Experiment 6 was conducted to readdress the speech rate findings of Experiment 1 and 2. There were no group differences on speech rate when examined quantitatively. However, the error analyses revealed that dyslexics were making twice the number of errors, as compared to CA controls. Thus, it is suggested that the speech rate task is an overestimation of the true speech rate ability of the participants. In the present study, we several practice sessions were administered prior to the speech rate task, to reduce the number of speech errors. The results show that the additional practice *increases* the speed for the dyslexics. However, it does not eliminate the problem of speech errors for either dyslexics or normal readers. Thus, it is suggested that the speech rate task is a poor index of the speed of access to underlying phonological representations. This is supported by the findings that speech rate does not correlate with either paired associate learning or phonological awareness tasks.

The final section of Chapter 6 is a comprehensive examination of the paired associate learning data from Experiments 3, 5, and 6. We find that both groups perform best in Experiment 3, compared to poorer performances in Experiments 5 and 6. Moreover, the error analyses from these studies suggest that RA controls committed approximately the same proportion of errors in each of the Experiments. However, dyslexics commit significantly more 'intra list' errors, and significantly fewer 'extra-list' errors in Experiment 3, than in Experiment 5 and 6, which in turn do not differ from each other.

Thus, it appears that dyslexics learn the verbal stimuli more easily in Experiment 3 compared to Experiments 5 and 6. However, they do show difficulty in linking the visual-verbal stimuli. In Experiments 5 and 6, dyslexics experienced more difficulty in learning the verbal stimuli than in Experiment 3, such that an accurate assessment of their 'linking' ability was difficult to obtain. The observed differences in dyslexics performance on the paired associate learning task across Experiments may have been a result of the visual stimuli, which were more concrete in Experiment 3. Plausibly, this allowed more capacity to be devoted to learning the visual-verbal associations.

The implications of this research are discussed in Chapter 7. It is concluded that verbal short term memory is not a primary deficit in dyslexic children. The findings suggest that verbal short term memory (memory span and speech rate) tap underlying phonological representations which are also required in setting up a reading system. However, memory span and speech rate tasks are less sensitive indices of the quality of the underlying phonological representations than phonological awareness (phoneme deletion, rhyme oddity) and verbal learning tasks (paired associate learning).

It is argued that the findings of the present research are best accommodated within a connectionist framework. There are at least two mechanisms required for setting up a reading system, phonological awareness and paired associate learning. In dyslexics, paired associate learning is less impaired, depending upon the severity of the phonological deficit. Phonological awareness, however, it more directly affected by phonological impairments, even if the impairment is mild. Finally, some limitations of the present research, and suggestions for future research are discussed.

Chapter One

The Development of Phonological Processing Skills

1.1 Introduction

One of the most important predictors of reading ability is phonological awareness. Although the finer points of this issue are still open to debate, it is generally accepted that phonological awareness skills are a necessary requirement for setting up an efficient reading system. Similarly, reading ability feeds back to boost phonological awareness skills. Thus, children who acquire the skill to reflect upon, and explicitly manipulate the constituent speech sounds of language, are capable of 'cracking the code'. However, although a vital skill, phonological awareness is not the only skill required to set up an efficient reading system. Indeed, learning to read requires that "a child's brain must engage in a combination of phonological processing, semantic processing and syntactic processing..." (Snowling, 1996, p.19).

This literature review will focus on phonological processing skills and their relationship to reading skill. Indeed, phonological processing skill encompasses more than just phonological awareness. Within this domain, we can also include verbal memory skills, and arguably, verbal learning skills. Thus, this review begins by discussing phonological awareness, and the reciprocal relationship between phonological awareness and reading skill. The development of the working memory system is discussed next, with particular focus on the relationship between memory span and speech rate. Finally, the relationship between verbal short term memory and reading skill is reviewed.

1.2 Phonological Awareness Skills and Reading Ability

Phonological awareness is commonly described as the ability to manipulate units of speech, such as syllables, onsets, rimes, and phonemes. Efforts of researchers world wide have clearly implicated phonology as a central component in reading development. However, while the importance of phonology is generally accepted, unresolved issues remain.

Goswami and Bryant (1990) developed one of the most influential theories regarding the development of phonological skills, and their relationship to reading. Based on early work (Bradley & Bryant, 1978; Goswami, 1986) Goswami and Bryant argue that words can be analysed at different levels. They emphasise the early development of the syllable, followed by the two units within the syllable, the onset and rime. Lastly, they emphasise that there are separable rhyme and segmentation factors within phonological awareness. According to their theory, awareness of the onset-rime segment of words is a precursor of reading development, and is causally related to children's reading achievement. They propose that smaller units, such as phonemes, develop later and are partly a consequence of reading development (Liberman, Shankweiler, Fisher, & Carter, 1974). However, a great deal of debate surrounds this theory.

Several methodologies have been used to investigate the interrelationship between phonological awareness and reading skill. Three main methodologies will be reviewed here: correlational and factorial studies, longitudinal studies, and training studies.

1.2.1 Correlational and Factorial Studies

Stanovich, Cunningham and Cramer (1984) were among the first investigators to conduct a correlational study investigating ten frequently used phonological awareness tasks. Moreover, they investigated the importance of kindergarten phonological skills on first grade reading achievement.

Phonological awareness tests, and measures of pre-reading skill were administered to 49 children, approximately six years old. Thirty-one subjects of the original 58 were available for follow-up testing in the following year. These children received tests of reading knowledge in addition to the battery of phonological awareness tests.

The results showed that there were strong intercorrelations between the seven non-rhyming tasks. When factor analyses were carried out, all seven non-rhyming tasks loaded highly on Factor 1, which accounted for 47.8% of the variance. The rhyme choice task had a moderate loading on Factor 1, although the remaining two rhyme tasks revealed only low loadings. These analyses showed that rhyme tasks were poor concurrent predictors of reading.

Next, the phonological awareness measures, and performance on the reading test administered at the end of Grade 1, were investigated. The results showed that all seven non-rhyming tasks correlated highly with the reading test. Furthermore, the group of readers was divided into skilled, and less skilled readers to investigate performance on phonological awareness tasks at different ability levels. All the measures differentiated the two groups, with the exception of the rhyming measures.

Finally, the skilled readers displayed ceiling effects on non-rhyming tasks in contrast to unskilled readers, who did not approach ceiling.

The results of this study confirm the importance of phonological awareness to reading attainment. They also reveal the relationship between the various tasks used to assess phonological awareness. A majority of tasks appeared to tap similar constructs, with the exception of rhyming tasks. On the basis of these results, Stanovich et al. (1984) suggested a one factor theory of phonological awareness. However, one limitation of this study was the relative ease of the rhyming tasks, which resulted in ceiling effects for the good readers. Plausibly, ceiling effects may have masked the existence of a rhyme factor.

Yopp (1988) carried out a comprehensive investigation into the nature of phonological tasks. One aim of the study was to determine the construct validity of each test and calculate its predictive validity in the initial stages of reading acquisition. A second aim was to factor analyse the tests to determine how many factors comprised phonological awareness. A third aim was to compute reliabilities for all the tasks in the experiment.

Ten phonological awareness tasks were administered to 109 children, aged five to six. The battery included tests of phoneme deletion, phoneme segmentation, and blending. A learning test was also administered to determine the predictive validity of each measure of phonemic awareness at the early stages of reading acquisition. This test measured children's ability and speed in nonword decoding; a test which taps knowledge of letter-sound correspondences.

The results of this study partially confirmed those of Stanovich et al.(1984). First, the different phonological awareness tasks ranged in their degree of difficulty. Second, the tests were highly intercorrelated, although they clustered into two main groups, or, factors. The tasks loading on Factor 1 were those which required subjects to perform only one cognitive function. The tasks loading highly on Factor 2 were those which required a series of steps to completion. Thus, Factor 1 comprised simple tasks, whereas Factor 2 comprised complex phonological tasks. These results were in direct contrast to previous findings (Valtin, 1984).

More recently, Hoien, Lundberg, Stanovich and Bjaalid (1995) conducted a series of studies investigating the factorial structure underlying phonological awareness in young children. Tests of rhyme, syllable segmentation, phoneme deletion, matching, blending and counting were administered. Principal components analyses revealed a three-factor solution. Tasks which loaded highly on the first factor were tests of phoneme blending, deletion, matching and counting; this was clearly a 'phoneme factor'. The syllable counting task loaded highly on the second factor, comprising the 'syllable factor'. Lastly, rhyme recognition loaded highly on the last factor, comprising the 'rhyme factor'.

In a second study, the test battery was re-administered, in addition to a test of word-reading skills, as the children were older. Tests of word-picture matching, and picture-word matching were used as measures of word reading. Results of this study again showed high intercorrelations between the phonological awareness tests. The highest intercorrelations were among the tests of phonemic awareness. Principal components analyses of the phonological awareness tests revealed a three-factor solution. Furthermore, the results of the analyses showed that phonological awareness contributed a significant amount of variance to reading skill, although it did not account for all of the variance in reading skill. This suggested that factors other than phonological awareness contributed to reading skill. Indeed, the phonemic factor was particularly strong, contributing more variance than the syllable or the rhyme factor. Specifically, initial phoneme identification, and final phoneme identification were the strongest predictors within the phoneme factor.

Thus, the results of Hoien et al. (1995) suggested that phonological awareness comprised three factors: phoneme, syllable, and rhyme. Moreover, the phoneme factor contributed the most variance to early word acquisition. This study confirmed previous findings of high intercorrelations among tests of phonological awareness (Stanovich et al., 1984; Yopp, 1988). The results were also consistent with the theoretical stance of Goswami and Bryant (1990). Indeed, rhyme emerged as a predictor, independent from phoneme and syllable factors. However, it should be noted that rhyme was *not more* important to early word acquisition, than phonemic awareness.

Clearly, there appear to be independent, yet highly intercorrelated factors comprising phonological awareness. However, the structure underpinning phonological awareness is dependent upon the tasks used. Thus, it remains unclear exactly how many factors comprise phonological awareness, based on the correlational data. Furthermore, there seems to be good evidence for a causal role of phonological awareness in reading attainment. However, the nature of the relationship between reading and phonological awareness cannot be fully elucidated by correlational studies, as they cannot determine causality.

1.2.2 Longitudinal Studies

Lundberg, Olofsson, and Wall (1980) conducted one of the earliest longitudinal studies investigating the relationship between phonological awareness and learning to read. Lundberg et al. (1980) examined the predictive power of different phonological awareness tasks, such as syllable and phoneme segmentation tasks, rhyme, and blending tasks to reading development.

A unique feature of this study was that the children were pre-readers. Children do not receive reading instruction until the age of seven in Scandinavian countries. Thus, the children were more cognitively mature than populations of English speaking pre-reading children, although the alphabetic code was still unknown to them. Pure measures of the relationship between phonological awareness and literacy acquisition could thus be obtained.

The children were administered nine phonological awareness tasks, and a measure of reading ability at the end of their kindergarten year. They were also administered an IQ test, a reading test, and a spelling task at the end of first grade, and six months later. The results showed that all the measures were highly correlated with later reading achievement, albeit to varying degrees. These analyses were especially strong considering IQ was held constant. This suggested a strong correlation between kindergarten phonological awareness and first grade reading skills, not attributable to general cognitive ability.

Furthermore, the correlations between kindergarten phonological awareness and first grade reading measures revealed high intercorrelations with phoneme reversal, and low correlations with syllable segmentation These results corroborated previous findings suggesting the importance of phonological analysis at the phonemic level. However, although Lundberg et al.'s (1980) study was a pioneering one, an important limitation was it failed to take into account pre-existing reading levels. The causal links between phonological awareness and reading could not be determined conclusively.

Bradley and Bryant (1983) conducted an influential study examining the role of phonological skills as a predictor of reading success in a four year longitudinal study. Three-hundred and sixty-eight four to five year olds were administered a sound categorisation task. The children were required to listen to lists of words, in which all but one word shared either an initial, medial, or final sound. The children were required to indicate the word that did not rhyme, or start with the same sound. Furthermore, memory span, vocabulary knowledge, and IQ were assessed. Three years on, children were administered tests of spelling, reading, and maths. Finally, they were re-assessed on an IQ test, and the sound categorisation task.

The results showed high correlations between the sound categorisation task and the three year re-test for reading and spelling. Correlations were considerably lower with maths skills. Interestingly, when age, IQ, memory for words and initial testing age were held constant, sound categorisation accounted for 4-10 % of the variance in reading attainment. Thus, sound categorisation skills was predictive of reading abilities three years later. Bradley and Bryant (1983) showed strong evidence for a relationship between phonological awareness and reading, independent of intelligence or memory abilities. These results were in line with the findings from Lundberg et al. (1980).

Wagner, Torgesen and Rashotte (1994) conducted a study to elucidate the nature and development of children's phonological processing abilities. One aim of the study was to determine the causal relationships between phonological processing skills and reading acquisition. Earlier cross-sectional work revealed that a five-factor model provided a good description of children's phonological processing abilities (Wagner, Torgesen, Laughon, Simmons, Rashotte, 1993). These five independent, yet highly intercorrelated latent factors comprising phonological processing skills were: phonological analysis, phonological synthesis, phonological coding in working memory, isolated naming, and serial naming.

Wagner et al. (1994) tested two hundred and forty-four children, over a 3 year period. All the children were administered a series of tasks tapping phonological analysis, phonological synthesis, working memory, naming, decoding, and measures of pre-reading, at each of the three testing times.

The results from the longitudinal correlational study fit a five factor model of children's phonological processing. Moreover, the five phonological processing factors appeared to develop at different rates. Phonological memory developed slowest, with the fastest rate of development for serial naming. Phonological analysis, synthesis and isolated naming fell in-between those extremes. The results of the study also found support for a reciprocal view of the relationship between children's phonological processing, and reading acquisition.

Muter, Hulme, Snowling and Taylor (1997) proposed that rhyme and phoneme awareness were separate sub-skills of phonological awareness. More specifically, they proposed that advanced phonological awareness skills such as segmentation, were unlikely to occur without reading instruction (Muter, Snowling & Taylor, 1994).

Conversely, easier segmentation skills were likely to occur without reading instruction.

In a follow-up study, Muter and Snowling (1998) investigated the relationships between reading, phonological awareness, and memory. Thirty-four children were administered a large battery of tests at three points over a two year period. Testing began in the nursery school year, with testing times two and three occurring during the primary school years.

A clear developmental progression was found across the three testing times. However, the pattern changed for testing times two and three. Neither rhyming nor segmentation showed effects on reading and spelling, whereas reading vocabulary at time two predicted reading at time three. Thus, early reading was most predictive of later reading.

Thus, longitudinal studies corroborate the findings from correlational studies. There is convincing evidence for at least two separable factors comprising phonological awareness (Muter et al., 1997; Wagner et al., 1994). Furthermore, there is strong evidence that different phonological skills follow different developmental patterns (Muter et al., 1997; Wagner et al., 1994).

1.2.3 Training Studies

One of the most useful approaches to testing causal relationships among phonological awareness skills, is the training study. If a specifically trained skill causes improvement in reading, the evidence for a causal relationship becomes very convincing.

Bradley and Bryant (1985) conducted an important longitudinal training study with 65 poor readers from their original longitudinal study. The children were divided into four groups to assess different forms of training on reading attainment. The first group received sound categorisation training only. The second group received sound categorisation linked with letter-sound knowledge training. The third group received conceptual categorisation, or semantic training, and sound categorisation training. The fourth group served as the control group and therefore received no training. The training groups received 40 individual sessions, once a week over a two year period.

The results showed that the concrete sound categorisation group performed best, followed by the sound categorisation group, then the conceptual categorisation group, and finally the control group. The concrete sound categorisation group progressed approximately nine months ahead of the conceptual control group in reading. This was notably more significant than the results for the sound categorisation groups' advantage over the conceptual categorisation group, which was a mere three months. Although positive trends were found suggesting an advantage for the sound categorisation group, they did not reach significance. Thus, Bradley and Bryant's results were in line with the view that phonological training facilitated reading development, but failed to make the argument definitively.

Byrne and Fielding-Barnsley (1991) conducted a longitudinal study using their training program, 'Sound Foundations'. The fundamental aim of the training program was to teach phonemic awareness, or, phoneme identity. 'Sound Foundations' was developed on the principle that different words begin or end with the same sound.

Sixty-four pre-school children were trained in groups of four to six, for half an hour per week for 12 weeks. The training program consisted of teaching children phonemes using posters and worksheets. For instance, when learning the letter /s/ , children were instructed to search posters and worksheets for all items beginning with /s/. All the children received feedback to assist learning the phonemes, and letter-sound relationships. The control group comprised 64 pre-school children, who received the same amount of exposure to the program. However, the control children were taught letters based on other criteria such as colour or shape.

The results showed a clear improvement in the training group throughout the course of the program. In contrast, the control children made only moderate gains. Furthermore, the training group was able to generalise their knowledge to phonemes they had not specifically learned in the training program. Lastly, the importance of phonemic training in conjunction with letter-sound training was highlighted when children from both control and training groups who were able to recognise phoneme identity, successfully completed a test of the alphabetic principle. The alphabetic principle was defined as :

> usable knowledge of the fact that phonemes can be represented by letters, such that whenever a particular phoneme occurs in a word, and in whatever position, it can be represented by the same letter (Byrne and Fielding-Barnsley, 1989, p.313).

A one-year follow up was carried out with the same groups of children. The test battery comprised phoneme identity, phoneme elision, alphabet knowledge, word identification, pseudo-word identification, and spelling tests. Overall, children who had grasped the alphabetic principle were better at reading real and pseudo-words than children who had not understood the concept. Children's pseudo-word reading was positively influenced by having grasped the alphabetic principle, as pseudo-words can only be decoded phonologically. Moreover, phonemic knowledge and alphabetic knowledge made important contributions to early reading development. Finally, two and three year follow-ups were conducted with the same children. Importantly, these studies showed that the children from the original training condition exhibited superior skills in decoding, three years after the initial intervention program.

Hatcher, Hulme, and Ellis (1994) conducted a study extending that of Bradley and Bryant (1985). They employed a large sample size, comprising children already identified as poor readers. The aims of the study were to investigate the effectiveness of three structured training programs with children who were experiencing reading difficulty. The research was conducted in the context of the 'phonological linkage hypothesis'. The primary tenet of this hypothesis was that an integrated program of letter knowledge and phoneme awareness was most effective for boosting reading development; children would learn to map sounds to letters, and apply this knowledge in reading.

Four groups of six to seven year old children, matched for IQ, were assembled. All the children were reading below the 10th centile. One group received reading with phonology training; a second received reading training alone. A third group received phonology training alone. The fourth group received no special training outside of normal classroom instruction, and any additional remediation that was given to them through the local education authority.

All the groups were tested at three separate times. The initial testing session occurred before the commencement of the training study, and included tests of general intelligence, reading, spelling, maths, memory and phonological skills. The second testing session occurred after the completion of the study. The third testing session, carried out nine months after the original training program was completed, was conducted to investigate the long term effects of the training study.

In the initial training program, the 'phonology alone group' received nine sets of phonological tasks based on previous research (Lewkowicz, 1980; Bradley & Bryant, 1983; Stanovich et al., 1984; Lundberg, Frost & Peterson, 1988). The integrated reading and phonology training group initially received four sessions. These sessions comprised teacher assessments of the children's responses to various tasks (e.g. letters, concepts about print, story writing ability, handwriting ability). The books used in all reading training came from various reading schemes employed in the schools. There were 73 books, divided into 20 levels (after the Reading Recovery Program). Constant links were drawn between phonology and reading throughout the sessions. The phonological linkage activities were inserted in the middle of each session and lasted approximately 10 minutes.

The reading alone group was taught with the same reading scheme as the combined reading and phonology group, without any explicit phonological training. Instead, more emphasis was placed on multi-sensory approaches to reading, such as building vocabulary, learning names of letters, reading books, context, and attempting unknown words.

Following the completion of the intervention program, improvements in the combined reading and phonology group were consistently larger than for the other three groups. The combined reading and phonology group performed significantly better than controls on tests of early word reading. The reading only group also performed significantly better than the controls. Furthermore, the results of the reading (word and nonword) and comprehension tests showed that the combined reading and phonology group performed significantly better than controls. Moreover, maths improvement was the same in all the groups, demonstrating the specificity of this training program to reading. Finally, analyses examining the long term effects of training showed reading improvements were largest in the combined reading and phonology group several months after the completion of testing, although the effects did begin to wane.

The results of this study demonstrated the importance of integrated phonological awareness and reading training for reading success. The group which received reading, or phonology training alone, did not improve as much as the combined reading and phonology group. Plausibly, the inclusion of a systematic and integrated approach to reading remediation could provide the skills for many poor readers to succeed in reading.

More recently, two large scale training studies were carried out by Schneider, Kuespert, Roth, and Vise (1997). One aim of the studies was to generalise the findings of Lundberg, Frost and Peterson (1988) to a population of German children. The German children began school one year earlier than the children in Lundberg et al.'s (1988) study. The German children studied here were therefore cognitively less mature. A second aim was to generalise the findings of Lundberg et al. (1988) using a less transparent orthography such as German. Finally, the study was conducted to investigate the role of the quality of teacher training on the long term effects of phonological awareness training.

The study began in the kindergarten year, when children were pre-tested with cognitive tasks measuring general IQ and phonological processing skills. Thereafter, the experimental training group was administered the training program. Following completion of the training program, both control and experimental training groups were post tested on the same tasks used in pre-testing.

The training program comprised six meta-linguistic units. The initial battery of tasks measured phonological awareness, phonological memory and speed of lexical access. Children also received tests of non-verbal IQ, tests of early literacy using letter knowledge, and reading of real and pseudo-words. Phonological awareness tasks included: initial phoneme deletion, phoneme blending, and phoneme analysis . The sound categorisation tasks were adapted from Bradley and Bryant (1985), using only alliteration and end sound portions. Tests of phonological memory and rapid naming were also included. Meta-linguistic tasks were administered in November 1992, to measure long term effects of the training program. Furthermore, comprehension and decoding skills were assessed at the end of Grades 1 and 2.

The results showed significant effects for all post-test measures of phonological awareness. Thus, training did improve children' phonological awareness skills. Moreover, rhyming tasks were easier than segmentation tasks. Furthermore, the quality of teacher training on the long term effects of phonological awareness training was investigated. The children were divided into 2 groups: consistently, and inconsistently trained children. Consistently trained children were taught by teachers who thoroughly completed the full training regime. Inconsistently trained children were taught by teachers who had missed a lesson, or failed to spend the allotted time on each lesson. The results showed that the consistently trained children performed better than the inconsistently trained children, and the control group. The inconsistently trained group and the control groups performed comparably.

Thus, it appears that the lack of long term effects were largely a consequence of differences in training. When the control group was compared to the group of consistently trained children, the consistently trained children performed better on 3 out of 6 meta-linguistic transfer tests (e.g. initial phoneme, word length, phoneme analysis). No differences were found between the inconsistently trained group and the control group.

A second study was conducted with the same children The aim of the second study was to improve teacher training quality. For instance, researchers met with teachers weekly, to discuss difficulties they were experiencing with the program. The results showed that children in the training program performed significantly better than the control children, corroborating the findings of Study 1. Furthermore, the long term effects of phonological awareness training were more robust in Study 2. Thus, the modifications in the training program made a considerable difference to the long term effectiveness of phonological awareness training.

Thus, the findings of Lundberg et al. (1988) were generalisable to younger children learning a language with a less transparent orthography. Interestingly, findings of the present study showed the dramatic impact of training quality. Importantly, the beneficial long term effects were confined to those children who had been consistently trained.

Thus, this study supported a causal view of phonological awareness to reading. However, the integration of phonological awareness and reading obviously yielded the greatest benefit (Hatcher et al., 1994). This study particularly emphasised the role of teacher training on the long term effects of phonological awareness training. The waning long term effects of integrated phonology and reading training in Hatcher et al. (1994), coupled with results of Schneider et al. (1997) highlight the importance of a carefully constructed training program.

Taken together, these studies demonstrate the importance of teaching phonological awareness in conjunction with letter-sound knowledge. Children who receive such training show obvious improvements in reading up to nine months after the cessation of the training program. This has been shown with children learning deep, as well as shallow orthographies. Longitudinal studies have also highlighted the importance of training quality. It appears that the quality of training which the children receive has an impact on the effectiveness of the training long term.

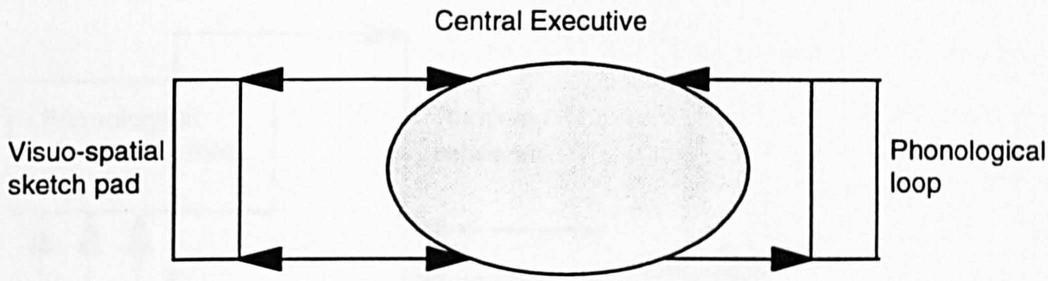
1.3 The Working Memory Model

Baddeley and Hitch (1974) developed one of the most influential models of working memory. They conceptualised this model as "a system for temporarily storing and manipulating information in the execution of complex cognitive tasks such as learning, reasoning, and comprehension" (Vallar & Shallice, 1990, p. 58). Figure 1.1 depicts the working model developed by Baddeley & Hitch (1974).

Figure 1.1

The Working Memory Model (Baddeley & Hitch, 1974)

(after Gathercole & Baddeley, 1993)



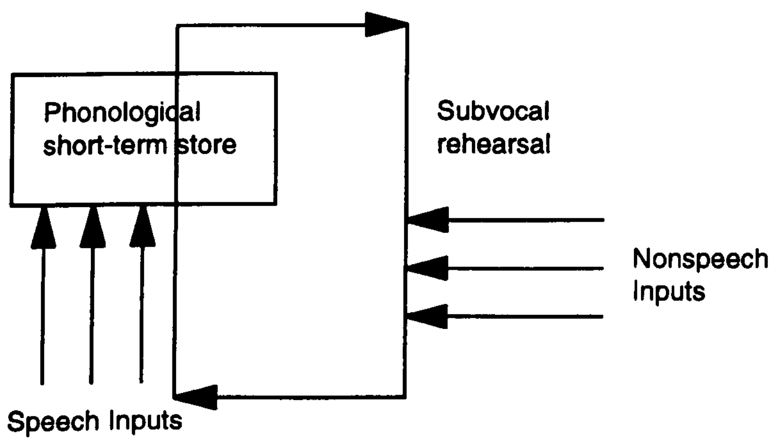
The model comprises three main sub-components: the central executive, visuo-spatial sketchpad, and the phonological loop. The central executive co-ordinates activity within working memory, and controls the transmission of information to the visuo-spatial sketchpad, and the phonological loop. The central executive is also responsible for retrieving information from long-term memory. The visuo-spatial sketchpad processes all the information which is encoded in the form of imagery.

The phonological loop is responsible for processing verbal information, specifically short term verbal information. Figure 1.2 depicts the phonological loop model based on Baddeley (1986).

Figure 1.2

The Phonological Loop (Baddeley, 1986)

(after Gathercole & Baddeley, 1993)



The phonological loop is conceptualised as a speech based mechanism, commonly described in terms of rehearsal processes and decay time. Rehearsal processes refer to sub-vocal rehearsal which occurs when remembering verbal information. Decay time refers to the time in which a letter sequence can be rehearsed and remembered without any degradation of the sequence. This time frame is approximately two seconds, and an impairment in memory results if this time is exceeded.

1.3.1 Empirical Evidence for The Working Memory Model

Four main bodies of research have demonstrated that verbal short term memory processes are speech based. Research with adult subjects has shown robust effects of phonological similarity, word length, and articulatory suppression. Phonological similarity refers to the degree of similarity between consonant strings, or words, in a memory span task. A subject's ability to remember the sequence in a memory span task is impaired if a sequence comprises items that are similar. Conversely, acoustically distinct sounds reduce the difficulty of the memory span task. This phenomenon is commonly referred to as the phonological similarity effect (PSE).

The word length effect occurs because long words are harder to recall than short words. This finding demonstrates that the duration of the items in memory is dependent upon the articulatory duration of the loop, not on the number of syllables the items contain.

Articulatory suppression is a technique used by researchers to identify the functions underlying short term memory span. Subjects are required to articulate irrelevant material, while presented with, and/or recalling the target lists in a verbal short term memory span task. This has been shown to impair verbal short term memory performance. Finally, a number of studies have investigated the unattended speech effect. The unattended speech effect refers to the finding that memory span is disrupted when subjects are required to complete a memory span task with irrelevant speech sounds in the background.

1.3.1.1 The Phonological Similarity Effect

Conrad and Hull (1964) conducted two studies investigating the effects of the acoustic nature of a vocabulary on error rates during recall of consonant vocabularies. Based on an earlier study by Conrad (1964), it was suggested that sequences of letters more acoustically confused in memory are more likely to be confused during recall, than sequences of letters selected from acoustically distinct vocabularies. Moreover, it was suggested that memory span might be more affected by the acoustic nature of a vocabulary, than the size of the vocabulary from which sequences are drawn.

The letter sequences were constructed from each of four vocabularies comprising consonants only (e.g. JKN (1); CDFHLNQYZ (2); FSX (3); BCDGMNPTV (4)). Vocabularies were chosen based on size (three vs. nine), and acoustic confusability (high vs. low). In other words, vocabulary 1 was three consonants in length with low acoustic confusability, and vocabulary 2 was nine consonants in length with low acoustic confusability. Vocabulary 3 was three consonants in length with high acoustic confusability, and vocabulary 4 was nine consonants in length with high acoustic confusability.

The findings of the two experiments were similar, and were therefore reported together. First, the results showed that the acoustically distinct and acoustically confusable three letter vocabularies were significantly different. Similarly, the acoustically distinct and acoustically confusable nine letter vocabularies were significantly different. Therefore, with vocabulary size held constant, recall was affected by the acoustic nature of the vocabulary. Furthermore, the nine-letter vocabulary low in acoustic confusability was significantly better than the three-letter vocabulary high in acoustic confusability.

However, a non-linear relationship was found between errors and the probability of acoustic confusion in the vocabularies. The results showed that the three-letter vocabulary low in acoustic confusability (e.g. vocabulary 1) had a greater percentage of wrong letters recalled than the nine-letter vocabulary low in acoustic confusability (e.g. vocabulary 2). Moreover, the three-letter vocabulary high in acoustic confusability (e.g. vocabulary 3) had approximately equal percentages of wrong letters recalled as the nine-letter vocabulary high in acoustic confusability (vocabulary 4). However, the differences between vocabularies 1–2 and 3-4 did not reach significance. Reasonably, the non-linear relationship between errors and probability of acoustic confusion was a result of sampling errors inherent in the sequences used in the experiment.

Thus, the results suggested that the acoustic nature of a vocabulary was an important factor in the ability to correctly recall consonant vocabularies. Indeed, the results suggested that the acoustic nature of a vocabulary was a more important factor in determining the accuracy of recall, than the vocabulary size from which the letter sequences were chosen. It was therefore suggested that the acoustic nature of items used in a memory span task was an important factor to consider.

Baddeley (1966) investigated the effects of acoustic similarity in a series of three experiments. Experiment one compared the acoustic and semantic similarity of word lists. Subjects were instructed to write the words in the correct order following the auditory presentation of the lists. The results showed that acoustically distinct lists were significantly easier to recall than acoustically similar lists. Semantically similar lists were significantly more difficult to recall than semantically different lists, although this effect was smaller than the acoustic confusability effect.

Experiment two aimed to separate the effects of acoustic similarity and formal similarity. Horowitz (1961) found that formal similarity (e.g. the degree to which the letters in any given word are common to the other words in the list) had an effect on short term memory, separate from acoustic similarity. Thus, experiment two included three lists of words. The first list comprised five words which were acoustically similar, but dissimilar in letter-structure. The second list comprised five words which were similar in letter structure, but dissimilar acoustically. The third list comprised five words of equal frequency, that sounded and looked dissimilar.

The results of experiment two confirmed the findings of experiment one. Acoustically similar lists were significantly more difficult than either of the other two lists. In contrast, there were no significant difference between formally similar and control sequences. The effects of acoustic similarity were further investigated with visually presented stimuli.

In a third experiment, subjects were presented with visual stimuli. Half of the words were acoustically similar, and the remaining half acoustically dissimilar. The results showed that acoustically similar sequences were significantly more difficult than acoustically distinct sequences, generalising the acoustic similarity effect to the visual modality.

Thus, the results of these experiments showed that the phonological similarity effect occurred across different modalities of presentation. Furthermore, these results showed that the short term memory store was particularly susceptible to phonological similarity, and not semantic or formal similarity. These results were taken as evidence that verbal short term memory was reliant on a phonological code.

1.3.1.2 The Word Length Effect

Baddeley, Thomson, and Buchanan (1975) investigated short term memory processes in a series of eight experiments, six of which will be reviewed here. The main aim of these studies was to compare the conceptualisation of short term memory as a function of temporal duration, and Miller's (1956) conceptualisation of short term memory as item based.

The first experiment was conducted to test the simple hypothesis that shorter words were easier to remember than longer words, commonly known as the word length effect. Words of one and five syllable lengths were used. The results showed that shorter words were easier to remember than longer words. However, a confounding factor in this experiment was the different linguistic structure of the short and long words.

In Experiments 2 through 4, Baddeley et al. (1975) further investigated factors affecting the word length effect. In Experiment 2, short and long country names were presented to the subjects. Importantly, the items had a similar frequency of repetition of the initial and final letters within the set of items. In Experiment 3, Baddeley et al. presented subjects with two lists of disyllabic words, again matched for frequency. The variable manipulated in this experiment was the spoken duration of the two pools of words; one pool was long in duration (e.g. harpoon) while the other set was short in duration (e.g. bishop). Finally, Experiment 4 was a replication and extension of Experiment 3. The procedure remained the same, except that the paced recall of the items was increased from two seconds, to one second.

Taken together, the results of these experiments demonstrated that the word length effect occurred irrespective of linguistic structure, and familiarity of the stimuli to the subjects. Moreover, word length affected memory span when both the number of phonemes and syllables were held constant. These results contradicted Miller's (1956) theory, which states that memory span is item based.

Experiment 5 was conducted to examine the effects of word length with visually presented materials. Two estimates of rehearsal were required for each subject. First, subjects were asked to read ten, five word lists of both long, and short items, as quickly as possible. Secondly, the subjects were asked to continuously repeat three of the words from one of the word pools aloud. Results showed that subjects recalled more short words correctly, than long words. Thus, a word length effect was found with acoustically presented material, and visually presented materials alike. This provided strong evidence for a speech based verbal short term memory store.

Baddeley et al. (1975) further hypothesised that if traces in short term memory decayed with time, rehearsal processes would be employed to revive the decaying traces. Thus, the amount recalled in a given amount of time, would be a function of rehearsal rate. Further analyses were carried out, and revealed that subjects were able to remember as many words as they could read in 1.6 seconds, or articulate in 1.3 seconds. The relationship between memory span and speech rate was further explored in Experiment Six.

The words used in Experiment 6 were of one, two, three, four, and five syllables. Reading rate was measured by instructing the subjects to read lists of words as quickly as possible. One and two syllable words were better recalled than three or four syllable words. Five syllable words were the most difficult to remember. Following this, memory span was plotted as a function of reading rate, to elucidate the span-rate relationship further. This demonstrated that reading rate was a good indicator of subjects' memory span, thereby supporting the trace decay theory.

Thus, this series of experiments provided support for the conceptualisation of short term memory as a function of temporal duration. In other words, subject's memory spans were determined by the amount they articulated in approximately two seconds, not the number of items to be remembered. Importantly, the relationship between memory span and speech rate has since been found to be robust across languages (Ellis & Hennelly, 1980; Naveh-Benjamin & Ayers, 1986).

1.3.1.3 Articulatory Suppression and the Unattended Speech Effect

Peterson and Johnson (1971) conducted a series of four experiments investigating the effects of articulatory suppression on visually and auditorally presented stimuli in a verbal short term memory task. The first two experiments investigated recall of visually presented stimuli. Recall was tested under conditions of articulatory suppression, in which the subject was required to count digits one through nine, and in a silent condition in which subjects were able to rehearse the sequences sub-vocally. Furthermore the stimuli varied in the degree of acoustic similarity. Lists comprising items of high acoustic similarity were more difficult to remember during articulatory suppression, than in the silent conditions. Moreover, articulatory suppression eliminated any beneficial effects of low acoustic similarity.

In a later series of studies, Baddeley et al. (1975) investigated the effects of articulatory suppression on the recall of auditory material of short and long items. Furthermore, the subjects were tested under suppression and no suppression conditions. The results showed that the word length effect was negatively affected under conditions of suppressions. A replication and extension of the study was carried out, to investigate visually *and* auditorally presented materials of short and long lengths under suppression and no suppression conditions. The results showed that the word length effect was abolished by articulatory suppression in the visual modality, but was comparatively unaffected in the auditory modality. A parsimonious account of these data is that the word length effect is not as severely impaired in the auditory modality because the material is already encoded appropriately. Thus, auditory material can largely bypass the articulatory loop, although not entirely. In contrast, the visual stimuli must first be recoded into a phonemic form, which necessarily requires the articulatory loop. When access to the articulatory loop is prevented by suppression, the word length effect is abolished.

Salamé and Baddeley (1982) conducted a series of studies investigating the effects of unattended speech on verbal short term memory tasks. Previous experiments investigating the unattended speech effect used white noise, producing equivocal results. In this study, Salamé and Baddeley (1982) substituted irrelevant speech for white noise. The aim was to investigate the role of semantic factors, sub-vocal rehearsal, and the phonological nature of memory items on the functioning of the verbal short term memory system.

Experiment one tested subjects' ability to complete a verbal short term memory task under two experimental conditions. One condition required subjects to complete the task, while simultaneously listening to monosyllabic words. A second condition required subjects to complete the task while listening to nonsense words. Subjects were instructed to ignore the irrelevant speech. A third control condition required subjects to complete the task under silent conditions. Importantly, the results of experiment one showed that irrelevant speech impaired the subjects' performance on the memory task. Irrelevant presentation of both words and nonword affected performance, suggesting that semantic factors did not produce the unattended speech effect.

A second experiment investigated the unattended speech effect under three experimental conditions. In one condition, meaningful words were presented before each of the digits. In a second condition, white noise was presented before each of the digits. A silent condition served as the control. Briefly, the results showed that presenting irrelevant sounds either prior to, or during the memory task affected memory performance. Irrelevant speech was more disruptive than irrelevant white noise, although this too produced some disruption.

A third experiment investigated the role of the articulatory loop in producing the unattended speech effect. Subjects were required to complete a memory span task for sequences of digits under four conditions. One condition required subjects to complete the task under conditions of irrelevant speech, and articulatory suppression. A second condition required subjects to perform under conditions of articulatory suppression. A third condition required subjects to perform under conditions of irrelevant speech. Finally, the fourth condition required subjects to complete the task under a silent condition.

The results of the study showed that the unattended speech effect disappeared under conditions of sub-vocal suppression. This suggested that the occurrence of the effect depended upon the articulatory loop. Alternatively, the effect could have occurred because it tapped a similar store as the articulatory loop. A further two experiments further investigated whether the occurrence of the unattended speech effect resulted from disruption in rehearsal processes.

Experiment four presented subjects with a quiet control condition, and two experimental conditions. The experimental conditions required subjects to complete the memory span task with irrelevant speech comprised of short words, and irrelevant speech comprised of long words. Briefly, results showed that the length of the words in the irrelevant speech did not have a differential effect on the amount of disruption. This results suggested that irrelevant speech did not disrupt memory via the articulatory loop itself. Instead, this result supported the argument that disruption occurred because the articulatory loop and irrelevant speech fed into a common system. In summary, the experiments suggested that the disruption of unattended speech is not a result of semantic information. Second, the results showed that verbal short term memory comprised two separate memory systems.

1.3.2 The Revised Working Memory Model

Clearly, the working memory model of short term memory processes (Baddeley & Hitch, 1974) accounted for phonological similarity effects, word length effects, and articulatory suppression. However, these effects were explicable within the working memory model only for auditorally presented materials; the unattended speech effect could not be explained.

Thus, the working memory model was re-conceptualised as a two component mechanism, comprising a phonological store, and articulatory rehearsal processes (Baddeley, 1986). Verbal material could be stored in the phonological store via articulatory rehearsal. Alternatively, the phonological store could be directly entered when articulatory processes were not required to process the information. Thus, when material was presented auditorally, it was automatically stored in the phonological store, bypassing the need for rehearsal. However, when material was presented visually, rehearsal was required to recode the visual information into a phonemic code. Only then could it gain access to the phonological store.

The findings from studies using articulatory suppression were reinterpreted in terms of the revised working memory model. The phonological similarity effect did not disappear with auditorally presented material because auditorally presented material was automatically directed into the phonological store. Hence, no rehearsal was necessary. In contrast, visually presented stimuli had to pass through the articulatory loop, to gain access to the phonological store.

The word length effect was simply a function of rehearsal. Thus, whether material was presented auditorally or visually, the articulatory loop could not be bypassed. However, to abolish the word length effect with auditorally presented material, suppression had to have occurred during *both* presentation and recall. This suggested that auditorally presented material was easier to rehearse, or, more compatible with articulatory processes, than visually presented material.

1.3.3 The Role of Long Term Memory in Verbal Short Term Memory

There is much evidence to support the view that there is a close relationship between memory span and reading rate or speech rate. However, there is a growing body of evidence to suggest that speech rate is not the only factor affecting short term memory performance. Several studies have implicated the role of long term memory in short term memory processes.

Hulme, Maughan, and Brown (1991) investigated the long term memory contribution to verbal short term memory in a series of two experiments. In the first study participants were instructed to recall words and nonwords of short, medium, and long spoken duration. The memory span task was presented with a beginning list length of two items, and increased by one until the subjects made errors on all four lists at any given length. Speech rate for items in the recall task was also measured by asking subjects to repeat pairs of items five times at each length.

The results of the memory span task indicated that nonwords were significantly more difficult to recall than words, and longer items were more difficult to recall than shorter items. The speech rate results showed that although there was a clear word length effect, there was no effect of lexicality. Thus, while items of different lengths have different rates at which they can be articulated, using words and nonwords with differing numbers of syllables, eliminated the absolute difference in articulatory speed between the two classes of items. In short, longer items were more difficult to articulate than shorter items, regardless of lexicality.

Furthermore, memory span was investigated as a function of speech rate to determine the role of the articulatory loop in memory span. These results demonstrated that the differences in recall of words and nonwords were not solely a function of speech rate. This supports a two component theory of short term memory; words benefit from long term memory representations, in addition to the short term representations in the articulatory loop.

A second experiment was carried out to further investigate the contribution from long term memory. Here, foreign words were used instead of nonwords. The advantage of using foreign words was that their meanings could be taught, making it possible to investigate the increase in recall as a function of the creation of long term memory representations. The items chosen were Italian nouns of short, medium, and long length. Equivalent lists of English words were also constructed. The experiment comprised a between groups comparison of memory span and speech rate for Italian and English words. First, memory span and speech rate was measured for the unfamiliar Italian words in one group. Following this, the subjects were taught the English translations for the Italian words, over a period of four days. Finally, their recall and speech rate for the Italian words was re-tested.

A second group was tested only on the English words. They also received a 'learning phase', wherein they were asked to learn the Italian translations of the English words, before a second testing session. Performance was not expected to change over the two testing times, because long term memory representations were already established for the English words.

The group learning the Italian words performed significantly worse at recalling the Italian words at the first time of testing compared to the second testing time. A word length effect was found at both testing times and an interaction indicated greater improvement for the longer items, compared to the shorter items. Speech rate analyses showed that longer words were more difficult to rehearse than shorter words. However, there was no effect of testing time. Finally, the relationship between memory span and speech rate showed that memory span and speech rate increased as a result of learning the English translations of the Italian words. Thus, there was some benefit of learning the long term memory representations for speech rate, as well as memory span.

There was a significant difference in performance between the two groups, demonstrating that memory span for the group learning the English words was higher than memory span for the group learning Italian words. More importantly, results showed that the learning stage had a greater effect on the recall of the group learning the Italian words and English definitions, than the group learning the English words and Italian definitions. Moreover, the results showed that speech rate for the group learning Italian words and English definitions was slower than for the group learning English words and Italian definitions of words. Furthermore, short words were easier than longer words.

Taken together, the results of the two experiments strongly suggest that there is a long term memory contribution to short term memory processes. This was most clearly demonstrated in Experiment 2. The performance of the group learning the Italian words and English definitions was compared to the group learning English words and Italian definitions of words. This comparison revealed that learning the English definitions had a greater effect on the memory span of the 'Italian word' group than did learning the Italian definitions in the 'English word' group.

Furthermore, the speech rate performance of both groups was compared across testing times, revealing no reliable differences.

Hulme, Roodenrys, Brown and Mercer (1995) investigated the role of long term memory in short term memory processes. Specifically, they investigated whether it was the availability of long term *phonological* representations which benefited verbal short term memory processes. Twenty-four students participated in the study, over a two day study. The stimuli used in the experiment were three sets of nonwords, of short, medium and long lengths, and an equivalent set of words. Memory span and speech rate measures were taken for each subject. Subjects were also presented with a familiarisation task, in which each subject had to repeat back the presented items.

On the second day, subjects were asked to complete the three tasks again. In addition they were instructed to fill out a questionnaire asking whether memory span was easier in the first or the second session. Furthermore, they were asked whether there was a difference in task difficulty dependent upon the lexicality of the items, and to suggest any strategies they used to complete the tasks. Finally, they were asked to rate the importance of familiarity with sounds of the non-words, associations between non-words and words, and associations between non-words and any meaning attached to them.

The results of the memory span data showed that the performance in the second session was better than the first. Moreover, words were better remembered than nonwords. The data also revealed that there was a greater increase between sessions one and two for the nonword stimuli, than the word stimuli. Moreover, shorter words were easier than longer words. The results of the speech rate data showed that the performance was better in the second session than in the first, and words were better remembered than nonwords. Shorter items were also better remembered than longer items. Furthermore, there was a larger increase in speech rate for nonwords, as compared to words.

When the memory span and speech rate relationship was further investigated, results showed that there were differences in memory span between words and nonwords which were not attributable to speech rate differences. The results of the questionnaire revealed that subjects rated familiarity of the sounds of nonwords as most important.

Thus, these findings replicated and extended the findings of Hulme et al. (1991), showing a long term memory contribution to short term memory processes. Moreover, it was the long term phonological representations which were beneficial to familiar words in a memory span task. Finally, availability of long term memory representations appeared to benefit the speech rate processes, which in turn boosted memory span performance.

In summary, there is a strong relationship between memory span and speech rate. Additionally, there appears to be a long term memory component to verbal short term memory. The long term memory component makes a beneficial contribution to memory span in two ways. First, it boosts memory span performance independently of speech rate processes. Secondly, it supports memory span performance via speech rate.

1.3.4 The Development of Working Memory

The working memory model has clearly accounted for much of the empirical evidence from adult studies. However, a model must also be able to account for the development of memory processes. Thus, the relevant literature on the development of verbal short term memory research will be reviewed.

1.3.4.1 Rehearsal Processes in Auditory Verbal Short Term Memory

Flavell, Beach, and Chinsky (1966) conducted a study investigating children's rehearsal processes in verbal short term memory. Sixty children, in kindergarten, second, and fifth grade participated in the study. Children were first trained in the procedure to point to each of a series of blocks in the same order as the experimenter. The experiment was conducted under an immediate recall, and a delayed recall condition. The immediate recall condition required the children to point to blocks in the same order, immediately following the experimenter. The delayed recall required children to observe the experimenter, and recall the blocks in the correct order following a fifteen second delay.

During both immediate and delayed recall, one experimenter trained in lip reading observed the children. Lip movement was considered an indication of covert verbalisation processes. The results showed that there was a steady increase in verbalisation commensurate with an age increase. There were no differences between the number of verbalisations elicited as a result of immediate or delayed recall. Thus, the results suggested that young children exhibited a deficit in verbal production.

However, later studies found a surprisingly consistent increase in memory span across development. Moreover, this increase in memory span was found to result directly from rehearsal processes, even in young children. Hulme, Thomson, Muir and Lawrence (1984) conducted a developmental study investigating the effects of word length on verbal short term memory span. They proposed two plausible hypotheses for the development underlying the increase in memory span. First, developmental increases in memory span could result from a capacity increase in the articulatory loop. Alternatively, greater speech efficiency could allow a greater number of words to fit into the two second duration of the articulatory loop, in older children and adults.

Thirty-six subjects, ranging in age from three to twenty-two years participated in the experiments. Three sets of one, two and three syllable words were used. The subjects were required to repeat back verbally the lists presented to them by the experimenter. Following each span test, subjects were asked to complete a speech rate task. They were presented with word pairs, and asked to repeat them ten times as quickly as possible. This was repeated twice with different word pairs at each length.

The results for the memory span data showed that older subjects recalled more words than the younger children. Furthermore, shorter words were easier to remember than longer words for all groups. Similarly, speech rate results showed that shorter words were easier to rehearse than longer words. There was also an increase in speech rate as age increased. Importantly, when memory span was plotted as a function of speech rate, subjects remembered as much as they recalled in approximately two seconds.

The results of a second experiment confirmed the overall memory span and speech rate findings of Experiment 1. Furthermore, Experiment 2 included alternative speech rate measures. The children were presented with a single word repetition task, and a speech rate task requiring the repetition of word triads. The results of the speech rate task showed that the repetition of triads was slower than the repetition of single words. A detailed analysis of the children's speech rate measures revealed that children learned to articulate individual words more quickly. The results suggested that the efficiency with which children learned to articulate individual words in the articulatory loop was responsible for an increase in memory span developmentally.

Hulme and Tordoff (1989) conducted two studies investigating the effects of word length and acoustic similarity on the recall and speech rate of children ages four seven, and ten. In the first experiment, children were administered recall and speech rate tasks, to investigate the effects of word length. Words of short, medium, and long spoken duration were used as stimuli in both tasks. Following this, children were administered a second recall and speech rate task, to investigate the effects of acoustic similarity. One set of six acoustically similar, and one set of six acoustically dissimilar words was used as stimuli in both the recall and speech rate tasks.

The results of the experiment showed that shorter words were easier to recall than longer words. Similarly, shorter words were easier to rehearse than longer words. Furthermore, older children performed better than younger children. The results of the experiment also revealed that the difference between recall for acoustically similar and dissimilar words was larger in the older groups, than in the 4 year old group. Plausibly, this was a results of floor effects in the 4 year old group. Moreover, speech rate for acoustically similar and dissimilar items showed that older children were able to rehearse the items more quickly than the younger children.

However, there were no differences between acoustically similar and dissimilar items in the speech rate task. This suggests that older children rehearsed all the items more quickly than younger children.

A second study was carried out to replicate the results of Experiment 1. However, to account for possible floor effects in the acoustically similar condition by the youngest group, an alternative memory span procedure was used. The results of this experiment showed that the effects of acoustic similarity on recall increased as age increased. Furthermore, the speech rate analyses revealed that older children rehearsed all the items more quickly than younger children. Moreover, all the children rehearsed acoustically dissimilar items more quickly than acoustically similar items. Finally, correlational analyses revealed a strong relationship between the size of the acoustic similarity effect and speech rate changes with age.

Taken together, the results suggest that word length increases as age increases. Moreover, the recall of word lists of different lengths is related to speech rate. Furthermore, acoustic similarity increasingly affects recall as age increases. This change is also related to speech rate changes with age.

The effects of word length can be accommodated within the Baddeley & Hitch (1974) working memory model. As children get older, their speech rate increases, which in turn increases the speed at which items are rehearsed in the articulatory loop. This increase in speed equally benefits words of all lengths. Futhermore, the acoustic similarity data is accommodated within the Baddeley & Hitch (1974) working memory model in the following way. Acoustically similar items lead to the creation of similar traces in the articulatory loop. These similar traces are more difficult to discriminate than distinct traces set up by acoustically dissimilar items. Reasonably, in a system where information decays over time, similar traces will be more severely affected than distinct traces.

Within this view, the effects of acoustic similarity are closely tied to rehearsal processes, or, the articulatory loop in Baddeley's (1986) model. This contradicts Baddeley's view that acoustic similarity effects occur in the phonological store. Baddeley argues that words gain direct access to the phonological store, as they are already phonemically recoded; confusable traces are then laid down. Thus, the revised working memory model cannot account for all of the available data from developmental memory research.

1.3.4.2 Rehearsal Processes in Visual Short Term Memory

The development of children's working memory has also been investigated in the visual modality. Early studies showed that there were large developmental progressions in children's storage strategies for visual materials (e.g. drawings) (Conrad, 1971). In other words, older children appeared to use sub-vocal rehearsal strategies, compared to younger children who did not. Hitch , Halliday, Dodd and Littler (1991) conducted a series of studies investigating the susceptibility of children to the word length and acoustic similarity effects in the visual modality. Two of the experiments will be reported here.

Two groups of thirty-six children took part. One group comprised children between the ages of four and five. The older group of children were aged between ten and eleven. Children were first trained in the memory span task for visual stimuli.

The stimuli comprised two sets of eight line drawings of objects, one and three syllables long.

Children were first trained under two conditions, 'silent' and 'label'. The 'silent' condition required the children to remain silent during stimuli presentation, and the 'label' condition required children to name the picture during presentation. All children were required to recall the names of the pictures in serial order, immediately after presentation. Following training, the two experimental conditions were presented to the children as in the training session.

Importantly, labeling enhanced younger children's recall. However, word length only affected young children in the 'label' condition. In contrast, a word length effect was found for older children in both 'silent' and 'label' conditions. Thus, it appears that younger children did not spontaneously utilise the articulatory loop, compared to older children.

Hitch et al. (1991) postulated that young children by-pass the articulatory loop and the phonological store for visually presented stimuli, using the articulatory loop only at output. Thus, young children did not encode and store the phonological features of memory items spontaneously. Alternatively, young children may have utilised the visuo-spatial component of working memory. Thus, it appears that establishing phonological representations in memory depended on the activation of covert rehearsal processes at *encoding*.

Hitch et al. (1991) carried out a second study investigating phonological similarity effects with children ages five and eleven. Again, two sets of eight line drawing were used, eight phonemically similar, and eight phonemically dissimilar words. Overall, similar items were more difficult to remember than dissimilar items. Older children also had longer memory spans than younger children. While the phonemic effect was present regardless of the condition for older children, it was only present for younger children in the 'label' condition.

Thus, younger children only showed phonemic similarity and word length effects, when they were encouraged to use the articulatory loop at encoding. Hitch et al. (1991) suggested that young children bypassed the articulatory processes and the phonological store in favour of visually encoding materials.

Henry (1991) investigated the word length and phonemic similarity effects in young children's short term memory. Sixty-four children, ages five to seven participated in the study. The stimuli were nine one-syllable words, and nine three and four syllable words. In the first session, measures of reading and vocabulary were administered. The second session comprised the span tests. A probed recall task was used to measure memory span, avoiding full verbal recall. Contrary to earlier developmental studies (Hulme et al., 1984), the results for the memory span task revealed that only seven year olds showed a word length effect.

A second experiment used a traditional memory span task. Twenty children aged five to seven participated in this study. The stimuli were identical to those in experiment one. The experimenter read out the words, and the child was required to repeat them back. Lists increased until the longest list length at which the child could correctly repeat two of the three trials. Both age groups demonstrated a word length effect. This was in contrast to the probed memory span task results, where only the seven year old children showed a word length effect. Taken together, these findings strongly suggested that word length effects are a consequence of output processes in very young children.

The final experiment investigated the acoustic similarity effect. Twenty-four children were presented with phonologically similar and dissimilar items auditorally. The spatial probe procedure of experiment one was used, requiring children to point to the picture corresponding to the word spoken by the experimenter. Seven year olds showed an acoustic similarity effect in this experiment, in contrast to the five year olds who did not.

Henry (1991) suggested that young children did not rehearse covertly. Rather, they appeared to use overt rehearsal processes. Under conditions of full verbal recall, the children were prompted to use verbal *output* rehearsal processes they would not normally engage in. This would explain word length effects in young children with span tasks requiring full verbal recall, and a lack of word length effects with probed memory recall tasks.

Similarly, the lack of a phonemic similarity effect in young children may have been an indication of their preference to code information visually. Thus, although a direct route to the phonological store was available, young children choose to ignore it in favour of a visual store. Auditory information may have been used only to strengthen their visual image of words.

Thus, there is conflicting evidence suggesting that the relationship between memory span and speech rate is not as intimate as was first thought. Developmental studies investigating verbal short term memory using a probed memory task, have shown that young children do not rehearse sub-vocally (Henry, 1991; Henry & Millar, 1991). Thus, word length effects found in earlier developmental studies have been reinterpreted as reflecting output effects, not the use of sub-vocal rehearsal. Furthermore, there is some evidence to suggest that young children only use sub-vocal rehearsal when overtly asked to do so (Hitch et al., 1991). Thus, the findings from developmental studies indicate that young children do not rehearse spontaneously, if at all.

1.3.4.3 The Role of Long Term Memory in Verbal Short Term Memory

Roodenrys, Hulme and Brown (1993) investigated the long term memory contribution to short term memory in children ages five and six, and nine and eleven. They were presented with lists of words and nonwords, comprising short, medium and long items. Children were presented with four lists of items at each length, beginning with two items for the young children, and three items for the older children. The list lengths increased until the children made errors on three lists within any list length. A speech rate task was administered following the span task. The child was presented with four pairs of words for each list length, and were required to repeat the pairs ten times as quickly as possible.

Overall, the results of the memory span analysis showed younger children performed worse than older children. Moreover, words were easier to recall than nonwords, and shorter items were easier to recall than longer items. The speech rate analysis showed that the older children performed better than younger children.

Furthermore, words were easier to rehearse than nonwords, and shorter items were easier to recall than longer items. The analyses also revealed an interaction between age and item type, resulting from larger differences in speech rate between items for the older, compared to the younger group. An interaction was also found between age and item length, which resulted from larger differences between short and medium length items for nonwords, compared to words.

The relationship between memory span and speech rate was investigated next. The slopes and intercepts were analysed separately to investigate the independent contributions from the articulatory loop and long term memory. The slope analysis revealed no significant differences between age group, or item type. However, the analysis of the intercepts revealed that the intercept was higher for words, than nonwords. There were no significant differences found between age groups.

Lastly, the memory span data was examined as a function of speech rate. This analysis revealed that there were significant differences between item types and age groups, even after speech rate had been accounted for. Therefore, the differences in memory span between age groups were not a simple function of speech rate. Moreover, the finding that words were easier to recall than nonword items, indicated that subjects benefited from the long term memory representations of words in a verbal short term memory task.

Thus, the relationship between speech rate and memory span is not as straightforward as was first thought. The data suggest that the retrieval of partially decayed phonological representations are supported by at least two mechanisms: articulation rate, and long term memory representations. The available evidence can be accommodated within a redintegration hypothesis (Schweickert, 1993).

Schweickert proposed that items could be reconstructed from a degraded trace through two processes. First, the degraded trace was transformed into a word, presumably from available long term memory representations of phonemes and words. This explained why word items had greater memory spans than nonwords, irrespective of length. A second process transformed the degraded trace into a string of phonemes. This accounted for novel word learning, such as children learning new words, or foreign language learning.

In summary, memory span can be increased via two mechanisms. First, memory span can be increased by changing properties of the items such as length. Shorter items can be rehearsed and recalled more quickly than longer items (Baddeley, 1986). In contrast, properties such as phonological similarity and lexicality are unaffected by speech rate. In this case, a memory span increase depends on the ease with which the degraded sequence can be reconstructed. Thus, items with easily available long term memory representations such as phonologically dissimilar, and word items, increase memory span. In contrast, phonologically similar or nonword items negatively affect memory span length.

1.3.4.4 The Interrelationship between Phonological Memory, Reading and Vocabulary Acquisition

Gathercole and colleagues have carried out numerous studies investigating the relationship between reading, vocabulary acquisition and phonological memory. In these studies, one of the tasks used to measure phonological memory is the Children's Test of Nonword Repetition (CNRep). This task is used primarily as a measure of phonological memory in young children, although there is some debate about the validity of this task (see Snowling, Chiat, & Hulme, 1991). In this task, children are administered ten nonwords each, of two, three, four, and five syllables. The children hear the item spoken aloud, and are asked to repeat the item. The remainder of this section will report the studies of Gathercole and colleagues, and their findings concerning the interrelationship between phonological memory, reading and vocabulary acquisition using the CNRep.

Gathercole and Baddeley (1989; 1993) investigated the role of phonological short term memory in the development of vocabulary in children in a four year longitudinal study, in which approximately 80 children was examined. All the children participated in each of the tasks over the four year period. The children were first tested at four years of age, and again at ages five, six, and eight.

All the children were administered tests of non-verbal intelligence, vocabulary, and phonological memory. Phonological memory tests included the Children's Test of Nonword Repetition (CNRep) (Gathercole, Willis, & Baddeley, 1994), a second repetition task, and a digit span task. The standardised repetition task was administered only to children ages four and five. Children at ages six and eight received the auditory digit span and the nonword repetition task. Lastly, tests of reading were also administered.

Significant correlations were found between all the phonological memory, and vocabulary measures at all four stages of testing. The correlations remained significant even after age, and nonverbal intelligence had been accounted for. Interestingly, the relationship between vocabulary and nonword repetition declined between the ages of six and eight in both sets of correlations.

To investigate the direction of causality between the measures, cross-lagged correlations were carried out, partialling out age, and non-verbal intelligence. The results showed that the direction of causality between vocabulary and phonological memory shifted between the ages of four and eight. Phonological memory at age four was causally related to vocabulary knowledge at age five. Conversely, vocabulary knowledge at age five was causally related to nonword repetition at age six. The relationship between vocabulary knowledge and nonword repetition at ages six and eight was non-significant.

Cross-lagged correlations partialling out vocabulary knowledge were carried out to account for any contribution of vocabulary knowledge to phonological memory at age four. The results of these analyses corroborated the initial findings. Lastly, additional analyses were carried out controlling for reading scores to address the possibility that the strong correlations were mediated by early reading ability. Results showed that phonological memory and vocabulary knowledge were not a result of an influence from reading.

In summary, results of the analyses showed that memory skills were strongly related to vocabulary development between the ages of four and five. However, a shift occurred between the ages of five and eight. This shift indicated that vocabulary development became an important predictor of phonological memory in the later stages of development.

Gathercole and Baddeley (1993) suggested that the causal relationship between vocabulary and phonological short term memory later on in reading development reflected the use of familiar phonological structures, reducing the demands of phonological memory. In other words, the extent of children's vocabularies, or, familiar phonological forms, influenced the degree of difficulty in retaining phonological forms in memory.

However, evidence from second language learning studies indicates that there may be an exception to the increasing causal relationship of vocabulary to phonological memory in later years of childhood. Service (1991) demonstrated that nine year old Finnish children learning English showed a strong predictive relationship between phonological memory and later success in acquiring English. Thus, in situations where lexical knowledge was insufficient to support phonological memory representations, the converse relationship between vocabulary and phonological memory persisted.

Gathercole, Willis and Baddeley (1991) further investigated the relationship between phonological memory, phonological awareness, reading, and vocabulary. Phonological memory and phonological awareness are two factors which have been shown to have strong associations with both reading and vocabulary development. However, it was unclear whether these two factors were part of a common phonological processing skill, or separate phonological abilities.

The results showed that phonological memory and phonological awareness both made unique contributions to vocabulary development, and reading ability. Furthermore, phonological memory and phonological awareness made a contribution as part of a *common* phonological processing component. Phonological memory and vocabulary knowledge analyses showed that memory skills were significantly related to vocabulary at both four and five years of age. Moreover, there was no significant relationship between rhyme and vocabulary. Finally, the relationship between phonological memory and reading emerged only in the five year old group, suggesting that the use of phonological memory was specific to a particular developmental stage, beginning around age five.

The main criticism of this work pertains to the nonword repetition task (CNRep). Some researchers claim that the CNRep task is not a pure measure of phonological memory, rather, it is a consequence of children's lexical knowledge (Snowling, Chiat, & Hulme, 1991). More recently, Gathercole (1995) conceded that vocabulary development had an impact on nonword repetition abilities, but maintained that phonological memory influenced vocabulary development independently of other phonological processing factors, if only to a small degree.

Following on from the work of Gathercole and colleagues, Bowey (1996) examined the contribution of phonological memory to vocabulary development, as measured by receptive vocabulary. Moreover, Bowey examined whether the link between phonological memory and receptive vocabulary was unique, or whether phonological memory also contributed to receptive grammar. Lastly, Bowey examined if phonological memory and phonological awareness were separate phonological processing abilities.

Approximately two hundred pre-reading children, ages four and five participated in the study. Tests of nonverbal intelligence, grammar, digit span, phonological awareness, phonological memory, and vocabulary were administered. To assess the specificity of the link between phonological memory and receptive vocabulary, regression analyses were carried out separately on receptive vocabulary and receptive grammar. The results of both regression analyses revealed that phonological memory and phonological awareness were both more strongly associated with receptive vocabulary, than with receptive grammar. Furthermore, regressions analyses on receptive vocabulary showed that phonological memory and phonological awareness were part of the same general processing factor; both of the factors accounted for equal, and overlapping proportions of variance in receptive vocabulary. Additional factor analyses also revealed that 51% of the variance in phonological memory and phonological awareness was accounted for by a single factor.

Thus, Bowey (1996) found evidence of a 'latent phonological processing ability comprised of phonological memory and phonological awareness (Snowling, Goulandris, Bowlby, & Howell, 1986; Snowling et al., 1991). Overall, phonological memory and phonological awareness were both equally associated with receptive vocabulary. Possibly, this latent ability may have reflected the "clarity of underlying phonological representations of speech..." (Bowey, 1990, p. 75). Thus, the claim that phonological memory makes an independent contribution was supported by the present study. However, phonological memory was not more strongly associated with vocabulary development than phonological awareness.

1.3.5 Criticisms of the Working Memory Model

According to the working memory model, there is a close relationship between rehearsal processes and verbal short term memory (Baddeley & Hitch, 1974; Baddeley, 1986). Moreover, recent evidence from developmental and adult studies summarised above, has shown that long term memory contributes to verbal short term memory beyond the contribution from rehearsal processes. Furthermore, studies suggest that the word length effect, seen as an indication of covert rehearsal processes, is actually a result of output effects. This brings into question the interpretation of word length effects in adult literature.

Cowan (1992) proposed an alternative conceptualisation of the working memory model. He suggested that covert rehearsal processes were involved in the re-activation of decaying traces during the interword interval, and not necessarily during recall of the items.

Forty-four children, four and five years of age participated in the study. The stimuli were eight phonologically similar and eight phonologically dissimilar items The list length started with two items, and increased in length until the child made a mistake on both lists at any length. Detailed measures of response time, pronunciation time, and speech time were taken to investigate both covert and overt rehearsal. Response time was the total time from the end of the stimulus presentation, to the end of the subjects' responses. Pronunciation time was the duration of the response from the beginning of the first word, to the end of the last word. Lastly, speech time was the total time of the subjects speech, excluding all of the interword pauses.

Briefly, the results showed that the three speech measures, response time, pronunciation time, and speech time were all highly correlated with memory span. This was the case for both phonologically similar and dissimilar lists. Furthermore, overt speaking rate was non-significantly correlated with memory span.

The results suggested that subjects with a longer memory span were not speaking faster, but utilised the interword pauses to reactivate decaying traces more efficiently, than subjects with a shorter memory span. Cowan favoured a memory search account of the results. In other words, subjects scanned through the lists of words during each interword pause, searching for the next correct item. The results of this study suggested that children with good memory spans were able to scan through more items in the interword pauses, than children with poorer memory spans. However, one limitation was that a speeded speech rate task was not included. Thus, the relationship between traditional speech rate and memory span measures, could not be contrasted with the trace decay and re-activation account of verbal short term memory.

Cowan, Keller, Hulme, Roodenrys, McDougall, and Rack (1994) included a speech rate measure, and examined word length and age effects on spoken recall in two groups of children. Sixteen four year olds comprised the young group, and twenty-three eight year olds comprised the older group. The stimuli included one, two and three syllable words. The list length was increased by one, until the subject made an error on three. The speech rate task required subjects to repeat four word pairs at each list length. Lastly, timing measurements of the memory span data were taken as in Cowan (1992). Specifically, timing measurements were taken for the mean preparatory interval, mean word duration, and mean interword pause duration.

First, Cowan et al. (1994) examined the memory span and speech rate data. Overall, memory span and speech rate analyses revealed the typical pattern of results found in previous studies (Hulme & Tordoff, 1989). Both data sets revealed main effects of age and word length. The relationship between memory span and speech rate was examined next. The analyses revealed a linear relationship, replicating previous findings (Hulme & Tordoff, 1989). Further analyses of the memory span and speech rate relationship were also carried out. The data were broken down into separate cells, such that the relationship for each age group and word length was determined. Interestingly, a linear relationship was not found. The correlations of the variables for the younger group was negative, compared to positive correlations between variables, for the older group. When the data from both groups was combined, a linear relationship re-emerged. This finding suggested that speech rate was not the only factor determining memory span.

The three timing measures, preparatory intervals, word duration, and interword pause durations, were examined next. The results of the analyses of preparatory intervals, with age and word length as factors, revealed main effects of age, but not word length. Interestingly, when a second analysis was conducted with the same factors, adding list length, main effects of list length were also found. This finding is consistent with previous results showing that memory search occurs during the preparatory interval (Sternberg, Wright, Knoll, & Monsell, 1980). The results of the analysis on word duration, with age and word length as factors revealed only small effects of list length. Lastly, the analyses on interword pause durations with the factors age and word length, revealed no significant effects. A second analysis was conducted with list length added as a factor. This analysis revealed main effects of list length. This finding is consistent with previous findings that list length affects pauses between spoken words in the response, and not the duration of words in the response (Cowan, 1992).

Thus far, the results showed that older subjects had shorter preparatory intervals than younger subjects. However, there were no age differences in word durations or interword pause duration. Importantly, there *were* large effects of list length. Thus, further analyses were carried out to determine the speed of processing in memory span tasks for younger and older children.

The two groups were compared on equivalent list lengths. The analyses of the preparatory intervals revealed shorter mean intervals for older, compared to younger subjects. Similar results were found for interword pauses. Once again, word duration was only affected by word length. Moreover, when the total response time was examined, a main effect of age emerged, reflecting longer response times in older subjects. Taken together, these results suggested that older subjects had quicker covert processing skills, resulting in faster re-activation. Ultimately, this extended the time they had to respond, without loosing the information needed in the span task.

Lastly, the relationship between speeded speech rate and the timing measures was examined. Surprisingly, different timing measures within each age and word length were not consistently related to memory span, nor to each other. However, the correlations between maximal speech rate and the preparatory interval of young children at each length was *positive*, compared to the *negative* correlation for older children. This indicated that young children spoke fast in the speech rate task, but were nonetheless slow in preparing their recall responses. In contrast, older children were quick at the speeded speech rate task, resulting in an equivalent increase in span length. A plausible account of this result, is that the subjects who had better memory spans were slower in their pronunciation times because the phonological representations were more complete, than subjects with poorer memory spans. This is consistent with the view that speech rate is not the only factor determining memory span.

Thus, the present study clearly showed that the relationship between memory span and speech rate is not as close as was first suggested. A dissociation between speech rate and memory span processes was demonstrated in younger children. Clearly, there are factors which contribute to memory span, separate from speech rate processes. Furthermore, the results of the study are inconsistent with a monotonic decay theory (Baddeley, 1986). Results do lend support to the hypothesis that memory span is a function of trace decay and re-activation processes in the interword intervals (Cowan, 1992). A parsimonious account of the available memory span data is that decay and re-activation in the interword pauses are a result of covert processes, whereas word length constrains memory span primarily through overt rehearsal.

In summary, there is a growing body of literature suggesting that the working memory model is no longer sufficient to account for the available empirical evidence. Although many newer models differ in their account of verbal short term memory phenomena (e.g. Brown & Hulme, 1995), they all suggest that there is more of a dissociation between memory span and speech rate than was originally postulated within the working memory model (Baddeley, 1986).

1.4 Summary

There is a strong body of evidence to suggest that phonological awareness is important in children's reading attainment (Bradley & Bryant, 1983; Goswami & Bryant, 1990). A child who has the ability to reflect on the component parts of words has the tools to 'crack the code'. Furthermore, evidence from the working memory literature suggests verbal working memory is speech based (Liberman et al., 1979). Thus, both phonological awareness and verbal memory tasks appear to tap the quality of the underlying phonological representations, also used in setting up a reading system.

Second, there is a large body of research demonstrating the strong relationship between memory span and speech rate. Furthermore, there is a developmental increase in memory span as children get older, which is a consequence of quicker rehearsal processes within the articulatory loop (Hulme et al., 1984). The robust finding of the word length effect is taken as evidence of this process.

However, Henry (1991) demonstrated that when a memory span task was administered which did not require overt rehearsal, young children did not show the word length effect. Thus, there is also convincing evidence to suggest that the word length effect is a consequence of output effects, and not rehearsal efficiency within the articulatory loop. Thus, there is an increasing body of research to suggest that the relationship between memory span and speech rate is not as close as was once assumed. Furthermore, this suggests that the working memory model is no longer sufficient to account for the available empirical evidence.

An alternative interpretation of verbal memory processes is that they are a function of decay and re-activation processes in the interword intervals (Cowan, 1992; Cowan et all., 1994). Thus, word length effects simply reflect the constraints put on memory span by overt rehearsal, not the covert processes responsible for re-activation of the items (e.g. Brown & Hulme, 1995).

Chapter Two

Developmental Dyslexia as a Verbal Deficit

2.1 Introduction

Dyslexia has generally been considered part of the continuum of language disorders. There is overwhelming evidence that children with dyslexia suffer from a wide range of language difficulties as revealed by their performance on spelling, verbal short term memory, phonological awareness and rapid naming tasks. Furthermore, adults with a history of dyslexia exhibit persistent difficulties with spelling, although they learn to compensate remarkably well in reading.

Definitions of dyslexia have developed considerably from the early days of reading disability research. A common definition of dyslexia in the 1960's and 70's was: "a disorder in children who, despite conventional classroom experience, fail to attain the language skills of reading, writing and spelling commensurate with their intellectual abilities " (World Federation of Neurology, 1967; cf. Fawcett, Nicolson, Dean, 1996, p.260)

However, there is a considerable amount of evidence over the past two decades, which has converged on the theory of a core phonological deficit of dyslexia. This has resulted in a revision of the old definition of dyslexia to: 'a specific language based disorder of constitutional origin, characterised by difficulties in single word decoding usually reflecting insufficient phonological processing abilities' (cf. Fawcett, Nicolson, & Dean, 1996, p.261)

A common criterion used in the assessment of dyslexic children is the discrepancy definition. The discrepancy definition is based on the assumption that there is a significant correlation between IQ and reading in the normal population. Thus, it is possible to determine the expected reading skills of children based on their IQ. When a child shows abnormally low reading skill in spite of their adequate IQ, the child can be assessed as dyslexic.

There are several criticisms of the discrepancy approach. Primarily, these criticisms stem from the use of IQ as the benchmark for the discrepancy. At best, IQ tests are measures of 'current cognitive functioning'. Thus, it is remarkable that the basis of the discrepancy definition rests on the blanket assumption that IQ measures are the best benchmark of a child's abilities.

Furthermore, there is a lack of agreement about which measures of IQ should be used. Some researchers suggest that a measure of comprehension would be more appropriate in identifying a child with reading disabilities (Stanovich, 1991). Lastly, a potential difficulty for discrepancy definitions results from evidence showing a reciprocal relationship between reading and cognitive abilities such as verbal intelligence and vocabulary. The existence of a reciprocal relationship muddies the argument that reading is discrepant from IQ or other cognitive abilities, and not vice versa. In short, the discrepancy definition of dyslexia is problematic. Nonetheless, it has been used extensively for the identification of children with specific reading difficulties, for clinicians and researchers alike.

In the present thesis, an educational psychologist had diagnosed all the dyslexic children as dyslexic. Furthermore, all the children had been statemented, and were referred to the experimenter by a special needs teacher, or an educational psychologist in the local education authority.

2.2 Cognitive Theories of Dyslexia

The most widely accepted cognitive theory of dyslexia is the phonological deficit hypothesis. The main tenet of this theory is that dyslexics suffer from core phonological problems. Before going on to describe this theory in detail, two alternative cognitive theories of the underlying causes of dyslexia will be discussed: the automatisation deficit hypothesis and the visual deficit hypothesis.

2.2.1 Automatisation Deficits

Nicolson and Fawcett (1989; 1995) have been the main proponents of the 'automatisation deficit'. They claim that there is a general lack of automaticity in dyslexics' skill acquisition. The main evidence on which Nicolson and Fawcett (1989) base this theory is that dyslexics are typically able to overcome their motor impairments by conscious effort, otherwise known as the 'conscious compensation' hypothesis.

Nicolson & Fawcett (1995) conducted a study comparing dyslexics and control subjects on a selection of tasks ranging from standard phonological and memory tasks, to gross and fine motor skill tasks. The results of this study showed that dyslexics suffered from reading and spelling difficulties compared to reading age controls. However, they also showed motor skill impairments compared to reading age controls. Furthermore, Nicolson and Fawcett claimed that the results of their analyses showed that the majority of the dyslexics showed deficits in the 'primitive' skills tested, such as balancing. In contrast, the majority of the controls did not show any impairment on these tasks.

More recently, Fawcett and Nicolson (1996) explained the automatisation hypothesis in terms of mild cerebellar dysfunction. The cerebellum has traditionally been considered responsible for motor control, although recent research has extended the scope of the cerebellum to the automatisation of both motor and cognitive skill automatisations (cf. Nicolson & Fawcett, 1996). In their study, Nicolson and Fawcett compared dyslexics and reading age control subjects on a battery of clinical cerebellar tests . These tests included the ability to maintain posture while pushed gently, and tests of muscle tone.

The results of this study showed that there was a 74% incidence rate for impairment across the fourteen tasks for the dyslexic group. This is in contrast to only a 16% incidence rate for the control group. Nicolson and Fawcett maintain that the mild cerebellar dysfunction is a plausible explanation of the dyslexics' motor and language difficulties.

A major problem with this type of evidence is that Nicolson and Fawcett do not discuss the issue of co-morbidity. In short, co-occurrences of dyslexia and motor impairments may give rise to their finding that dyslexia is caused by a mild cerebellar dysfunction.

2.2.2 Visual Deficits

Hogben (1997) summarised two main theories of visual deficits in dyslexia. The first theory is called the 'transient-on-sustained inhibition' theory. The transient visual system, or, magnocellular system, is defined as a "system [which] responds preferentially to lower spatial frequency and higher temporal frequency stimulation [;] it responds to the onset and offset of stimuli, and its responses are both rapid and brief" (Snowling & Hulme, 1994, p.59). In contrast ,the sustained, or parvocellular system, is defined as a :

> system [which] exhibits responses that are slower and more enduring than those of the transient system [;] it is sensitive to higher spatial frequencies, and is colour-selective.....it distinguishes between patches of colour that are of different hue even though they may be of the same luminance" (Snowling & Hulme, 1994, p. 59-60).

Briefly, the primary tenet of this theory is that dyslexics have a deficient transient visual pathway which fails to inhibit the sustained visual pathway during a saccade (e.g. a brief rapid eye movement between fixation points). In essence, the transient system is weak and fails to function properly. This results in the contents of one fixation carrying into the next. Thus, when dyslexics read text, words become cluttered and indecipherable. This would be analogous to attempting to read two words printed on top of one another.

A great deal of empirical work supporting a low-level transient visual deficit comes from Lovegrove and colleagues. Lovegrove, Martin and Slaghuis (1986) claimed that dyslexic children have low level impairments of the transient visual system, on the basis of evidence suggesting they exhibit abnormally low sensitivity to abstract patterns and less sensitivity to low spatial frequencies. However, as pointed out by Hulme (1988), Lovegove et al. (1986) do not sufficiently indicate that low level transient system deficits are causally related to dyslexia.

Hulme (1988) pointed out two limitations of Lovegrove et al.'s (1986) theory. First, they only found a correlation between an impairment in the transient system and poor reading. Second, the theory implies that dyslexics should show more difficulty in prose reading, than in single word reading tasks. In contrast, several studies have shown that children with reading difficulties show improved reading on prose tasks, compared to single word reading. Lastly, a commonly held view is that visual deficits affect a small proportion of children. In contrast, Lovegrove et al. (1986) stated that visual problems occurred in approximately 75% of the children they studied. This seems an unlikely high number of children suffering from visual problems.

The second theory of a visual deficit in dyslexia is the 'temporal precedence' theory. This theory states the transient and sustained visual pathways work in conjunction. The transient system is seen as the first stage in visual analysis. This system "extracts large amounts of global information"(Snowling & Hulme, 1994, p.64). This is followed by the second stage in the visual analysis - the sustained system. This system is concerned with more detailed functions of analysing shape, and colour, for instance. In essence, if the operation of the transient system is slow, information transfer to the sustained system is delayed, causing problems in the efficiency with which the visual system analyses text.

The main criticism of this theory stems from the lack of evidence. There is little known about the interaction between the transient and sustained visual systems. Furthermore, the only empirical work conducted to support this theory used a visual search task (Williams, Brannan, & Lartigue, 1987, cf. Hogben, 1997). The validity and reliability of this task is not known, leaving serious doubts about its implications about reading difficulties.

Alternative visual deficit theories state that difficulties with eye tracking or eye-dominance are causally related to reading disability. Dunlop, Dunlop and Fenelon (1973), conducted an experiment investigating the dominant and reference eye of dyslexics. It was hypothesised that dyslexics had a reference eye which was on the opposite side of their preferred hand. This was thought to underpin perceptual problems. Stein and Fowler (1982), studied this theory of eye dominance problems as well, claiming that dyslexics would not show a dominant eye in testing. Both studies failed to show conclusively that eye dominance had any impact on reading development in dyslexics. Furthermore, re-analysis of Stein and Fowler's data by Bishop (1989), found no support for the importance of ocular dominance as a causal determinant of dyslexia.

Thus, it appears evidence for a visual deficit in reading disability is tenuous at best, although it is premature to rule out visual deficits in reading disability. The nature of the relationship between visual deficits and reading disability is far from clear. In contrast, there is a large body of empirical evidence pointing to specific verbal language deficits in dyslexia.

2.2.3 The Phonological Deficit Hypothesis

Vellutino (1979) first proposed the verbal deficit hypothesis of dyslexia. Until that time, dyslexia had been thought of primarily as a perceptual deficit, possibly caused by neurological deficiencies. The basis of the perceptual deficit stemmed from studies, which showed that dyslexics typically reversed letters such as *b* and *d,* or familiar looking words such as *saw* and *was* (Vellutino , 1979, p.335). However, there was a lack of evidence to suggest that this spatial confusion generalised to other situations. Alternatively, Vellutino suggested that verbal deficiencies underpinned visual difficulties. Indeed, some research had shown that confusion errors accounted for only a small proportion of errors in a list of words, which were easily, confused (Liberman, Shankweiler, Orlando, Harris & Berti, 1971).

Furthermore, Vellutino and colleagues showed that when children saw confusable items, they did not actually misperceive the items spatially. These children had difficulty in the visual-verbal associations, or, the labeling of the items. In other words, the verbal coding of the items was inaccurate. This inaccuracy occurred more with confusable items because of the similar constituent phonemes, such as *saw* and *was.*

The phonological deficit hypothesis is a refinement of the verbal deficit hypothesis, originally proposed by Vellutino (1979). It is widely accepted as the primary underlying deficit in dyslexic readers' difficulties in reading and spelling. At the cognitive level, the phonological deficit comprises poorly specified phonological representations, which manifest themselves at the behavioural level as poor naming, phonological awareness, and memory skills (Frith, 1997). Ultimately, this results in poor reading and spelling abilities.

2.2.3.1 Phonological Awareness

It is well documented that dyslexic readers have language difficulties, which stem from problems with phonology. Indeed, dyslexics typically lack phonological awareness, or, the ability to reflect explicitly on the sound structure of language (Bradley and Bryant, 1985; Manis, Custodio & Szeszulski, 1983).

Bradley and Bryant have conducted some of the most influential work demonstrating the relationship between phonological awareness and learning to read. Moreover, they have conducted research showing the predictive role of phonological awareness in reading attainment. Bradley & Bryant (1978) conducted a study in which dyslexic readers were compared with a reading age control group on a sound categorisation task. The results of this study showed that dyslexic children were worse on this task than younger children matched for reading age. Thus, poor sound categorisation skills were not simply a consequence of poor reading skills.

Bruck (1992) carried out a study involving school age dyslexic children ranging in age from 8 to 16. The dyslexic children were compared to chronological age and reading age controls. A group of adult dyslexics was also tested. This group was matched with a reading age control group comprised of grade 3 children, and a chronological age control group, comprised of college students. The battery of tests administered included measures of syllable counting, onset, rime, and phoneme counting and phoneme deletion.

The results showed that dyslexic children and adults performed below age appropriate levels. Thus, it appears that dyslexics never attain age appropriate phonological awareness, although adult subjects did perform age appropriately on some simpler phonological awareness tests such as awareness of onsets. Furthermore, the dyslexic groups were also compared to younger reading age controls. These analyses revealed that the dyslexic children were worse than reading age control children on all the measures. The adults performed comparably to grade 3 normal readers on syllable counting and onset deletion items. Thus, dyslexic children showed little development in their phonological awareness as their reading skills increased.

Snowling and Goulandris (1994) conducted a longitudinal study investigating the development of dyslexic readers' reading, spelling, and phonological skills. The dyslexic sample was matched with CA and RA controls. All the children were administered tests of reading skills (words and nonwords) and a spelling task. Furthermore, they were administered tests of rhyme oddity and rhyme production. The rhyme production task required the children to generate strings of words to rhyme with a spoken target. Finally, they were administered a verbal repetition test comprising words and nonwords, a digit span test, and a picture naming task.

At testing time 1, the dyslexic group showed poorer performance on all the measures compared to CA controls, but showed a similar pattern of performance to younger reading age matched controls in reading, spelling, and phonological awareness skills. Two years later, the dyslexic children showed significantly less improvement than the normal readers did on tests of reading. Thus, although the groups had been matched at time 1, the groups now differed. A similar pattern of performance was found for spelling. Indeed, their spelling progressed even more slowly than would be predicted from their reading progress. Finally, their phonological awareness skills were reassessed. These results showed that dyslexics were worse on a difficult version of the rhyme oddity and the rhyme production tasks. Furthermore, they were worse than controls on repetition of words and nonwords.

Perhaps some of the most compelling evidence demonstrating the phonological difficulties of dyslexic children comes from a study conducted by Scarborough (1990). Scarborough followed three groups of children from the ages of 30 months, until grade 2. The three groups of children comprised children at genetic risk of dyslexia, who later became dyslexic themselves, children at genetic risk of dyslexia, who became normal readers, and controls who were selected to match the dyslexic group on measures of IQ, socio-economic status, and sex.

Measures of natural language production, in combination with measures of productive syntax were taken. Phonological production, and lexical diversity were also measured. Furthermore, the children were re-assessed at 60 months, on measures of sound and letter knowledge, and phonological awareness. The results showed that children who later become dyslexic, exhibited difficulties with *pre-literacy* skills, including vocabulary, rhyme skills, and phoneme awareness. Moreover, these children produced shorter sentences, which were often syntactically simpler than those produced by children who become normal readers. These differences were evident as early as 3 years of age.

Another task that has been used frequently to test the phonological deficit hypothesis has been the nonword reading task. An important advantage of using nonword reading is that the processes it engages are equivalent to the processes used in learning to read. Nonwords can only be pronounced using spelling-sound rules. Therefore, if a dyslexic reader has difficulty in decoding, as the phonological deficit hypothesis posits, then nonword word reading should be impaired. Thus, it 'gives a relatively direct indication of phonological reading skill.'(Hulme & Snowling, 1993, p.286).

An early study by Snowling (1980) investigated the nonword reading abilities of dyslexic and normal readers. The children were presented with pairs of one-syllable nonsense words presented in within-modality (e.g. auditory-auditory: A-A; visual-visual: V-V), and in cross-modal conditions (auditory-visual: A-V; visual-auditory: V-A). The children were instructed to identify whether the pairs of nonsense words were the same, or different (e.g. sint-sint; torp-trop).

The results showed that the groups performed comparably in the A-A condition, indicating that the dyslexics did not suffer from auditory discrimination difficulties. However, there were group differences on the V-V conditions. The performance of normal readers improved with increasing reading age, compared to dyslexic readers who did not. One interpretation of this result was that the normal readers invoked a speech-based strategy, despite the visual presentations, compared to dyslexic readers who relied solely on a visual strategy. Indeed, the results of the cross-modal conditions supported this interpretation. Cross-modal conditions require the decoding of the presented stimuli across modality. Normal readers performed similarly on V-V, A-V, and V-A conditions, suggesting that they invoked a phonological strategy, even in the V-V condition. In contrast, the dyslexics were significantly better in the V-V condition, compared to the cross-modal conditions, suggesting that they were able to use visual memory effectively, rather than a decoding strategy. Importantly, the biggest difference between groups occurred in the V-A condition - the condition most similar to reading.

Snowling (1981) further investigated nonword reading in dyslexic subjects, compared to normal reading matched controls. The subjects were required to read one and two syllable nonwords, comprised of zero (e.g. wut; tegwop), one (e.g. blem; twamket), or two consonant clusters. The time to read each of the stimuli was recorded. The results showed that the dyslexics were more error prone than normal readers. Interestingly, the dyslexics did not differ from younger reading age matched controls on one-syllable items, although they were worse on two-syllable items. Moreover, the errors were most pronounced in the items containing the consonant clusters.

Holligan and Johnston (1988) investigated normal and dyslexic ability to read irregular and regular words, of high and low frequency. In addition, subjects were required to read pseudohomophones and control nonwords. The results showed that the groups did not differ in word reading. However, dyslexics were worse on both nonword reading tasks, compared to normal readers. Interestingly, when the dyslexics were tested on a further set of nonwords comprising only three letters, they were comparable to younger reading age controls. These results corroborated the findings of Snowling (1981).

However, although there is considerable evidence in support of a nonword reading deficit, some studies have found contradictory results (Johnson, Rug, & Scott, 1987; Vellutino & Scanlon, 1987). One of the first studies to dispute a nonword reading deficit was that of Beech and Harding (1984) (cf. Rack, Snowling, & Olson, 1994). Dyslexics and reading age controls were presented with regular words (e.g. suffer) exception words (e.g. sugar) and nonwords (e.g. suther). Furthermore, the items in each condition were of either one or two syllables. The results showed that both groups read the real words equally well. Surprisingly, both groups also read the nonwords equally badly. Thus, the results of this study supported a developmental delay hypothesis, rather than a deficit hypothesis.

A recent meta-analysis by Rack, Snowling and Olson (1994) reviewed the available literature on nonword reading. Rack et al., (1994) suggested that the bulk of the evidence favours a nonword reading deficit. Some possibilities for the discrepancies in the literature could be accounted for by methodological inconsistencies including, but not limited to, the age of the subjects, the complexity of the materials, and the effects of teaching. Thus, it is reasonable to conclude that dyslexics do suffer from a nonword reading deficit, which is underpinned by their phonological difficulties.

2.2.3.2 Verbal Short Term Memory

Dyslexic readers typically exhibit difficulties with verbal short-term memory. There is a large literature suggesting that reading disabled children have difficulties with serial recall tasks involving digit span, or letter sequences (Torgesen & Houck, 1980; Jorm, 1983).

Hulme (1981) conducted a study investigating the serial order memory of reading disabled and normal readers. Ten year old reading disabled, age matched control, and reading age matched control children were presented with letter strings of six to eight letters long. In one condition, the children were asked to point, and then name the visually presented letters. In a second condition, the children were asked to trace, and then name the letters. Following this, the children were presented with all 14 letters and asked to pick out the correct letters, after which they were required to arrange them in the order they were initially presented. The data showed that the reading disabled children were worse than chronological age matched controls, in the 'point and name' condition only. Moreover, the reading disabled children did not differ from the reading age matched controls. Furthermore, Hulme's analysis allowed for the independent investigation of group differences for order and item memory . These results showed that reading disabled children did not differ from age matched, or reading age matched children for order memory. Thus, this study suggests that dyslexic children had difficulties only with item memory, and not necessarily memory for serial order.

The research on verbal memory span of dyslexic children suggests that dyslexics have verbal memory span impairments compared to their normal readers. However, a further focus of interest has been whether poor readers show a deficit in the phonological encoding of verbal material in memory tasks (cf. Johnston, Rugg, & Scott, 1987, p.205). As discussed in Chapter 1, good readers experience a disruption in serial recall paradigms when phonologically confusable items are used (Conrad and Hull, 1964; Hitch & Halliday, 1983).

Shankweiler, Liberman, Mark, Fowler and Fischer (1979) conducted a study investigating the ability of good, marginal and poor readers to differentiate between phonologically confusable (e.g. b, c, d, g) and phonologically distinct (e.g. h, k, q, w) letters using a serial recall paradigm. The results showed that the good readers made fewer recall errors than either the marginal or poor group. The good readers also showed a greater short-term memory benefit from phonologically distinct lists than either of the two poor groups. Similar results were found in a study that presented materials auditorally. Thus, the results suggested that poor reading children had phonological difficulties, which underpinned their difficulties with serial short-term memory tasks. They suggested that good and poor readers differed in their ability to utilise the speech code in verbal short-term memory. Furthermore, they suggested that poor readers did not have sufficient availability to the phonetic representations, which in turn caused difficulties with rehearsal processes (see also Brady, Shankweiler, & Mann, 1983).

Following on from the work of Shankweiler et al. (1979), Siegel and Linder (1984) conducted a study involving reading disabled, arithmetic disabled and normal reading children, on a series of short-term memory span tasks. The children ranged in age from 7 to 13. The results showed that younger reading disabled and arithmetically disabled children did not show the phonetic confusability effect, replicating the findings of Shankweiler et al. (1979). In contrast, older poor reading and arithmetically disabled children did show a phonetic confusability effect, although they were still less sensitive to similar sounding letters than the normal reading children. Thus, Siegel and Linder suggested that children did eventually develop sensitivity to similar sounding letters, although this ability was developmentally delayed (see also Olson, Davidson, Kliegl, & Davies, 1984). Moreover, short-term memory difficulties extended beyond reading, into other cognitive domains, such as arithmetic.

However, there is some evidence suggesting that young dyslexic children *are* sensitive to phonological similarity. Johnson (1982) conducted a study in which 9, 12, and 14-year-old dyslexic children were auditorally presented with phonologically confusable and phonologically distinct stimuli. Importantly, the groups of dyslexic children were matched with a reading age and a chronological age control group. The results of the study revealed that the children did show a phonetic confusability effect when presented with auditorally presented stimuli. Although dyslexics were poorer on overall recall, they were no worse than their reading age matched controls. Moreover, all the groups were equally disrupted by phonologically similar items, which contradicts the findings of Shankweiler et al. (1979). However, Johnson (1982) tested older children than Shankweiler et al (1979) and there is some evidence to suggest that older poor readers do develop some phonological sensitivity (Siegel & Linder, 1984; Olson et al., 1984).

2.2.3.3 Speech Perception

Snowling, Goulandris, Bowlby and Howell (1986) conducted a study investigating speech perception and reading skills in dyslexics, RA and CA controls. Based on the work of Brady et al., (1983) Snowling et al. tested the participants' ability to repeat real and nonsense words presented with and without noise. Furthermore, the word lists were of high and low frequency, and the nonwords were comprised of the high and low frequency lists.

The results showed that all three groups were of similar ability in repeating high frequency words. Moreover, dyslexics were comparable to RA controls on low frequency words. Furthermore, dyslexics were worse than both RA and CA controls on nonword repetition. Thus, dyslexics appeared to show a deficit in their non-lexical processing, although their lexical processing was as good as would be predicted from their reading age.

Furthermore, noise affected all three groups equally. This finding contradicts the results of Brady et al. (1983), who showed that noise negatively affected dyslexics' performance more than good readers. Plausibly, the different findings can be accounted for by procedural differences, suggesting that dyslexics do not actually suffer more in a repetition task in noise than normal readers.

A second experiment was carried out to investigate the performance of dyslexics and normal readers on an auditory lexical decision task, using high and low frequency words and nonwords. The nonwords were constructed from the list of words. The results of this experiment showed that dyslexics had more difficulty making lexical decisions than CA controls, performing only as well as younger RA controls.

Taken together, the results of this experiment suggested that dyslexics showed a developmental lag in the acquisition of lexical knowledge. They performed significantly worse than CA controls on a lexical decision task, although comparably to younger RA controls. However, dyslexics did show a deficit in non-lexical processing, demonstrated by their poor performance compared to CA and RA controls. Furthermore, the dyslexics were comparable to CA and RA controls in the noise conditions. Thus, dyslexics did not appear to have difficulty at input. Snowling et al. (1986) suggested that dyslexics had difficulty analysing speech into its constituent parts. This affected the efficiency with which they used phonological speech codes, which in turn affected verbal memory abilities.

Johnston, Rugg and Scott (1987) conducted a study with two 8 and two 11-year-old poor reading groups. One poor reading group at each age comprising a poor reading group with below average IQ, and the other average IQ. Each poor reading group was matched with a chronological age control group and a reading age matched group. Thus, for each age group, there were low ability poor readers, average ability poor readers, chronological age normal readers and reading age controls. The children were administered a serial memory span task in which they had to recall individual letters from phonologically similar and phonologically distinct lists.

The results showed that the older children had longer memory spans than younger children. Moreover, chronological age controls had longer memory spans than the other three groups. Furthermore, the average intelligence poor readers performed similarly to the reading age controls, while the below average poor readers performed worse than the reading age and chronological age controls. They also performed as well as their average poor reading peers. Correlations between reading ability and memory span revealed a moderate association in the average poor reading group, and a weaker relationship between the two variables in the poor reading group with the below average IQ. Finally, the analyses revealed that dissimilar lists were easier to recall than similar lists.

Thus, this study showed that even young eight-year-old dyslexics showed phonological sensitivity, compared to their reading and chronological age controls. This study contradicts the findings of Shankweiler et al. (1979) and Siegel and Linder (1984). However, upon closer examination it is apparent that the task difficulty in the present study was lower than in previous studies in which the poor readers did not show phonological sensitivity. In the present study, all the groups were able to recall at least 50% of the items, compared to approximately 30% of the items in previous studies. Thus, it appears that when task demands are high, readers abandon verbal rehearsal and fail to show phonological similarity effects (see also Hall, Wilson, Humphreys, Tinzmann, & Bowyer, 1983).

2.2.3.4 Verbal Memory, Phonological Awareness, and Reading Ability

As discussed in Chapter 1, there is convincing evidence to suggest that there is a relationship between verbal memory and phonological awareness. Wagner et al. (1993) conducted a cross-sectional study of 184 normal readers in kindergarten and second grades. The results of this study showed that there were five distinct but correlated factors which comprised phonological processing abilities: phonological analysis, phonological synthesis, phonological coding in working memory, isolated naming and serial naming.

Furthermore, Wagner, Torgesen & Rashotte (1994), confirmed the initial findings of a 5 factor model of children's phonological processing. Interestingly, the study revealed that there were different rates of phonological processing development. Phonological memory developed slowest, and serial naming the fastest, while phonological analysis, synthesis, and isolated naming falling in-between extremes. Taken together, Wagner and colleagues suggested that both phonological awareness and memory span tasks tap the quality of underlying phonological representations. Importantly, it was the quality of the underlying phonological representations which affected children's reading ability.

There have also been a number of studies investigating the relationship between verbal memory, phonological awareness and reading attainment in dyslexic readers. Torgeson, Rashotte, Greenstein, Houck and Portes (1987) conducted a study comparing dyslexic children with a low digit span score, dyslexic children with a normal digit span score, and normal readers on sound blending tests. All the children were administered the reading and mathematics portions of the Wide Range

Achievement Test (Jastak & Jastak, 1978). Following this, the children were presented with flashcards that had either single letters, consonant blends and digraphs, or single words, or multisyllabic words on them. The children were asked to sound out the item on each card. Finally, the children were administered a subtest from the Illinois Test of Psycholinguistic Abilities (Kirk, McCarthy, & Kirk, 1968). The children were required to listen to a word or nonword spoken aloud in its segmented form, after which the child was asked to verbalise the word in its blended form (e.g. c-a-t→cat).

The results for the sound blending tasks showed that the dyslexic group with a poor digit span score was significantly worse on single syllable words than either of the two groups, who in turn did not differ from one another. However, on the more difficult multisyllabic items, both the dyslexic groups were significantly worse than the normal readers, but did not differ from each other. Thus, the results suggested that dyslexic children with poor verbal memory span experience difficulty at a more basic level than dyslexic children who were not identified as having poor verbal memory spans. However, both groups of dyslexics were unable to cope with complex sound blending, with multi-syllabic words.

McDougall, Hulme and Ellis and Monk (1994) investigated the relationship among memory span and reading skill in good, average and poor readers. McDougall et al. (1994) conducted a study with good, average, and poor readers on tests of memory span and speech rate, coupled with tests of phonological awareness. The findings of this study showed that the level of reading skill was on a par with the level of memory span. Interestingly, memory span differences were well accounted for by speech rate differences between groups. Moreover, speech rate predicted independent variance in reading skills better than verbal short term memory.

This study suggested that poor memory span was a consequence of poor speech rate. Speech rate was affected by the underlying phonological representations in the articulatory loop. Thus, verbal short-term memory difficulties were not causally related to reading difficulties, rather they were an index of the underlying phonological deficit. Moreover, speech rate was a better index of the underlying deficit than memory span.

2.3 Verbal Long Term Memory

2.3.1 Paired Associate Learning in Normal Populations

Paired associate learning is the term used to describe the process of learning to associate a stimulus item with a response item. Researchers have focused on a variety of factors affecting paired associate learning skills, ranging from the imagery of pictures and the concreteness of nouns, to the effectiveness of learning strategies.

Paivio & Yarmey (1966) investigated the paired associate learning ability of adults using pictures and words in adults. Specifically, they examined the 'conceptual peg' hypothesis. This hypothesis states that the stimulus in a paired associate task functions as a 'peg', facilitating the association of the response to the stimulus. However, the effectiveness of the stimulus as a 'peg' depends upon the capacity of the stimulus to arouse images, which facilitate response recall. This theory predicts that pictures are stronger 'pegs' than words in the stimulus position, because they directly arouse concrete images.

Participants were required to complete a paired associate learning task under four conditions. The first condition comprised pictures in both the stimulus and response positions. The second condition comprised pictures in the stimulus position, and words in the response position. The third condition comprised words in the stimulus, and pictures in the response position. Condition four comprised words in both stimulus and response positions.

The results showed that subjects recalled pictures better than words on the stimulus side. Moreover, pictures in the stimulus position facilitated paired associate learning regardless of whether the response item was a word or a picture. However, pictures facilitated paired associate learning most when the response was a word. In contrast, pictures did not have a facilatory effect on the response side. Thus, the results of this experiment supported the 'conceptual peg' hypothesis.

Following on from the work of Paivio & Yarmey (1966), Dilley & Paivio (1968) conducted a similar study with nursery, kindergarten and first grade children. The children were tested under the same four conditions used by Paivio & Yarmey (1966), although the stimuli used in the condition were drawing of objects familiar to young children, and their corresponding concrete names (e.g. hat-star).

The results of the study showed that children recalled pictures better than words in the *stimulus* position. Conversely, children recalled words better than pictures in the *response* position. Interestingly, pictures in the response position hindered paired associate learning more for children, than adults. Plausibly, this could have resulted from children's difficulty in retrieving, and verbalising the pictorial response.

Thus, consistent with the results of Paivio & Yarmey (1966), the combination of the pictorial stimulus and a verbal response provided maximum facilitation in paired associate learning. Paivio and colleagues have consistently shown positive effects of pictorial stimuli in paired associate learning, with both adults and children. Moreover, they have demonstrated a hierarchy of facilitating factors of stimuli in paired associate learning; pictures surpass the facilitory effects of concrete nouns, which surpass the facilitory effects of abstract nouns. On the response side, pictures hinder learning more so than concreteness, which is less facilitative than when on the stimulus side. Taken together, this work supports the 'conceptual peg' hypothesis.

Learning strategies, and the development of these strategies has also been examined a good deal. Martin, Boersma, & Cox (1965) conducted two studies investigating the relationship between learning strategies and the rate of acquisition in paired associate learning. Briefly, Martin and colleagues categorised the strategies according to a scale of complexity. For instance, rote rehearsal techniques were less complex than a technique that required an elaboration linking the two items. Importantly, this study showed that there was a positive relationship between the complexity of the strategy used, and the correct performance on paired associate learning. Moreover, the strategy that facilitated learning most was the use of a 'syntactical' strategy, also called 'relational elaboration'. In this strategy, the participant formed a relationship between the stimulus and response items, to make the representations more salient in working memory (e.g. *cat-chair* $\rightarrow$ the *cat* is under the *chair*.

Pressley & Levin (1977) were among the first researchers to investigate the development of the relationship between strategy use and performance on paired associate learning. Children ages 11, 13, and 15, were presented with 25 pairs of concrete nouns. The subjects were presented with the pairs, followed by an interview about the techniques they used to remember the pairs. The subjects were classified into 'rehearsers', 'elaborators' or 'mixed strategy' users. Importantly, the results of the analyses showed that the proportion of subjects who used rehearsal decreased as the children got older. Conversely, the proportion of subjects who used an elaborational technique increased with age. Interestingly, a subjects preferred strategy was a good predictor of individual differences, not just differences between groups based on age.

Following on from the work of Pressley & Levin (1977), Beuhring and Kee (1987) conducted a study examining the developmental increase in elaborational techniques in paired associate learning, as a function of increased awareness about memory processes, and strategies, also called metamemory. Fifth and twelfth grade readers participated in the study. They were tested on their ability to associate noun pairs, and their knowledge of metamemory. The children were presented with sample memory tasks and required to judge which strategy would be most efficient in learning the pairs. For example, the children were presented with lists of opposite and arbitrary paired associates (e.g. Black-White; Mary-Walk) and asked to judge which paired associates would be easier to learn. There were a total of nine different types of paired associates, and/or strategy plans the students were asked to judge.

Older students tended to use elaborative, or other associate strategies more so than younger children, who relied more heavily on rote rehearsal techniques. Regressions analyses examining the relationship between strategy use and recall performance revealed that elaborative strategy accounted for 42% of the total variance in the recall task. Importantly, age related factors only accounted for approximately 4% of the total variance in recall performance. Thus, strategy use was indicative of age related differences, as well as individual differences. Furthermore, performance on the metamemory task and strategy use were examined in a regression analysis. Importantly, most of the developmental increase in the use of associative memory strategies could be explained by development in metamemory knowledge.

More recently, Guttentag (1995) conducted a series of three experiments investigating strategy use in paired associate learning, in 11 and 12 year old normal readers. First, Guttentag examined the automatic encoding of meaningful associations using accessible and inaccessible pairs of words under conditions of deliberate, and incidental learning. Accessible items were those items for which the stimulus nouns evoked the correct response even in the absence of an opportunity to study the pairs; inaccessible items were the converse.

In the deliberate condition, subjects were instructed to learn the pairs via a cued-recall test. In the incidental learning condition, subjects were first asked to rate the 'pleasantness' of the items followed by a surprise cued-recall task. Secondly, Guttentag examined the ease with which elaboration strategies were used, as indexed by the speed of the strategy use. Lastly, Guttentag examined the strategy use with both accessible and inaccessible pairs of items, using a 'think aloud' procedure. This required the subjects to verbalise their chosen strategy during the task. Importantly, the results showed that children using an elaboration strategy were more successful in recalling the pairs of items. Furthermore, accessible items were recalled more readily than inaccessible items.

Taken together, these studies showed a developmental trend in the use of associative learning strategies. Moreover, the evidence suggested that this development was dependent upon the maturation of metamemory. Furthermore, there was a relationship between strategy use and performance on paired associate learning. Complex strategies such as elaboration, resulted in a better performance on learning tasks, than less involved strategies, such as rote rehearsal. Interestingly, strategy use appeared to be a good indicator of age related group, and individual differences alike.

2.3.2 Paired Associate Learning in Dyslexic Readers

Fildes (1921) was among the first researcher to investigate paired associate learning in reading disabled and normal reading children. This study was among the first to show that disabled readers were poorer than normal readers on paired associate learning tasks. Several studies confirmed this finding, even when I.Q was held constant (Otto, 1960; Brewer, 1967).

Vellutino, Steger, Harding, and Phillips (1975) and Swanson (1978) were among the first researchers to distinguish between dyslexics' difficulties with visual-verbal paired associates compared to normal performance on visual-visual paired associates. Vellutino et al. conducted a large scale study with fifth and sixth grade good and poor readers. The children were tested on three different paired associate tasks. First, children were tested on paired associates comprising ambiguous visual stimuli paired with non-verbal auditory stimuli. Second, children were tested on visual-verbal pairs where the visual stimuli comprised ambiguous animal like shapes. The non-verbal stimuli comprised CVC trigrams (e.g. WIB, PEX, MOG, YAG). Finally, children in were presented with visual-verbal pairs in which the verbal stimuli comprised CVC trigrams, and visual stimuli comprised Sanskrit letters.

The poor readers were worse on both types of paired associates, comprising the CVC trigrams. Furthermore, dyslexics committed more semantic 'real word errors' on the tasks than did normal readers. The error analyses conducted by Vellutino et al. (1975), suggested that the groups differed most dramatically in the case of 'syllable substitutions'. Closer scrutiny of the syllable substitution errors revealed that there was a difference in the number of phonemic and semantic substitutions committed among the groups, within the syllable substitution error category. The data revealed that poor readers' errors comprised 'real' words, compared to normal readers' errors which were most often novel combinations of the phonemes comprising the target items. Unfortunately, Vellutino et al. did not provide examples of the errors for scrutiny. Thus, Vellutino et al. suggested that "poor readers association difficulties [were] not unique to orthographic structures, but may instead, be a manifestation of basic dysfunction in the labeling process (Vellutino et al., 1975, p.80).

Following on from the work of Vellutino et al. (1975), Swanson (1978) investigated the hypothesis that dyslexics' suffered from verbal encoding difficulties. In this study, children were presented with six nonsense shapes paired with familiar real words, under two conditions. In the first condition, children were trained on the visual-verbal pairs (e.g. named condition). In a second condition, children were shown the shapes and trained on the contours of the shapes only (e.g. unnamed condition).

The results showed that reading disabled children were worse overall than normal readers on the first paired associate learning task. The dyslexic and normal readers did not differ on paired associate learning in the unnamed condition. Moreover, normal readers benefited from the named condition, compared to the unnamed condition. Importantly, there was a significant difference between normal readers and dyslexics in the named condition, while there was no difference between groups in the unnamed condition. These findings suggested that attaching a verbal label to an unfamiliar shape did not help to integrate information for dyslexic readers.

Gascon and Goodglass (1980) investigated the effect of discriminable features on paired associate learning, analogous to the 'conceptual peg' hypothesis (Paivio & Yarmey, 1966). The visual stimuli varied in informational content. Items high in visual information comprised three dimensional clay figures, and items low in visual information comprised simple two dimensional unfamiliar shapes. Similarly, auditory information was varied in informational content. Auditory stimuli high in information comprised CVC nonsense syllables (e.g. frag), and auditory stimuli low in information comprised VC combinations (e.g. ib), unlike English words.

The results of the associative naming task showed that normal readers made significantly fewer errors regardless of the condition, than did disabled readers. Moreover, visually rich stimuli enhanced recognition for both groups, compared to auditory enriched stimuli, which did not reach significance. Furthermore, the results from the recall task revealed that normal readers made fewer matching errors than poor readers. The visually rich stimuli enhanced recall, more for the poor, than the good readers. Again, auditory rich stimuli did not enhance recall on its own, although the combination of auditory and visually rich stimuli enhanced association and recall the most.

Thus, consistent with previous findings, dyslexics were inferior to normal readers on auditory-visual associations (Fildes, 1921; Brewer, 1967). Moreover, this study supported the findings of Paivio & Yarmey (1966). However, there were several methodological weaknesses in this study. First, the visual stimuli were not rated for associability, nor were the CVC trigrams objectively rated for word-likeness. Finally, the CVC trigrams included a consonant cluster at the beginning or end of each syllable. Plausibly, this could have increased item difficulty compared to items that comprised single phonemes. Thus, the finding that visually rich stimuli enhanced association and recall more than auditory rich stimuli may have been a consequence of poor stimuli selection, rather than support for the 'conceptual peg' hypothesis (Paivio & Yarmey, 1966).

Hulme (1981) conducted a series of experiments investigating dyslexic and normal reading children on visual and verbal memory tasks. Hulme (1981) concluded that "[dyslexics'] problems in learning to read is unlikely to be one of remembering the visual configurations of words, but rather one of learning the verbal labels of these configurations"(Hulme , 1981, p.146).

Hulme (1981) suggested that paired associate learning was akin to learning new words. Moreover, paired associate learning was particularly sensitive to the strategy used by reading disabled children learning novel words. Evidence from other research suggests that reading disabled children have difficulty segmenting new words and often look at them as whole, unique entities. Indeed, an earlier study by Torgesen and Goldman (1977) examined strategy use in second grade good and poor readers. This study was a replication and extension of a study conducted by Flavell, Beach & Chinsky (1966) mentioned in Chapter 1. Good and poor readers were administered a vocabulary test followed by a memory task using the same procedure as Flavell, Beach & Chinsky (1966) (see Chapter 1).

The results showed that good readers verbalised, and recalled more than poor readers. Moreover, when the two groups were questioned about the strategies they used, poor readers appeared unaware of possible strategies to employ in the task. Furthermore, of the poor readers who admitted to employing a rehearsal strategy, the poor readers used the strategy less consistently than good readers. Thus, the findings of the experiment supported the hypothesis that poor readers were more inefficient than good readers in using learning strategies.

Vellutino, Scanlon and Spearing (1995) conducted a series of experiments investigating the semantic and phonological coding abilities of good and poor readers. In one experiment, Vellutino et al. administered a paired associate task comprised of Chinese ideographs, matched with either high, or low meaning words. The results showed that both good and poor readers found it easier to learn associates of high meaning words than associates of low meaning words. Importantly, good readers performed significantly better than poor readers overall. Vellutino and colleagues suggested that visual-verbal learning was partially determined by the ability to store the verbal component in working memory, consistent with the work of Baddeley et al. (1986).

In a second experiment, Vellutino et al., (1995) altered the paired associate task to mimic the reading process more effectively. Novel alphabetic characters were used as the visual stimuli, substituting them for the Chinese ideographs used in the first experiment. The verbal stimuli were either concrete or abstract words. Furthermore, the subjects were administered two paired associate tasks. One was to investigate initial learning, the second to investigate transfer of knowledge. Only the results of the first paired associate task will be reviewed here. Finally, the visual processing abilities of the good and poor readers was assessed using a visual recognition test.

The results of the PA task showed that pairs with concrete response items were easier to recall than pairs with an abstract word in the response position. Furthermore, there were significant differences between reading ability groups, with good readers performing significantly better than poor readers. Plausibly this may have been a result of differences in the ability to store the verbal component in working memory. Furthermore, the results of the visual recognition task revealed no significant differences between reading groups. This suggests that the reading difficulties were not related to deficits in visual processing abilities.

Recently, Wimmer, Mayringer, and Landerl (1997) conducted a study with dyslexic and normal readers. Children were administered a pseudoword learning task, in which they were asked to associate a novel name with a novel toy. The results of the learning task revealed that dyslexics took twice as long to reach the learning criterion as controls. Moreover, many dyslexics were unable to learn the names to criterion entirely.

Taken together, these studies shows that dyslexics experience great difficulties in paired associate learning involving a verbal component, compared to normal readers. However, it is unclear from the available evidence, whether dyslexics found it difficult to learn the verbal label, or whether they experienced difficulty integrating the visual-verbal associates.

2.3.3 Phonological Skills in New Word Learning

There has been recent interest in using the paired associate learning paradigm to investigate word learning in children. Gathercole, Hitch, Service, and Martin (1997) investigated word learning in five year old children. Children were required to complete two measures of phonological short term memory, digit span and nonword repetition. Furthermore, the children were required to complete tests of vocabulary, and nonverbal abilities. Lastly, they were administered four word learning tasks. Two of the learning tasks involved associating pairs of words, and word-nonword pairs. The remaining two learning tests required the recall of definitions, and the recall of new words. These novel words were taught using a story learning paradigm.

Both measures of phonological memory were significantly associated with vocabulary, although nonword repetition showed stronger associations than digit span. Further analyses showed that digit span and nonword repetition were both significantly associated with the word-nonword learning tasks, and the recall of new names task. Interestingly, nonword repetition was also significantly correlated with recall of definitions. Neither of the phonological memory measures was significantly associated with word-word learning. These results suggest that phonological memory capacity specifically constrained children's ability to learn novel phonological sequences.

Lastly, the relationship between vocabulary knowledge and new word learning was investigated. There was a stronger relationship between children's existing vocabulary knowledge and novel word learning, than between vocabulary knowledge and familiar word learning. These results suggest that vocabulary knowledge supported both phonological and non-phonological components of nonverbal word learning.

Thus, the results suggested that children's ability to learn novel stimuli was supported by their ability to hold items in short term memory, *and* by their existing vocabulary knowledge. Interestingly, the ability to link familiar words was not supported by phonological memory, or existing vocabulary knowledge. Gathercole, Hitch, Service and Martin (1997) suggested that there was a dissociation between phonological and nonphonological long term learning. Furthermore, the results showed that there was a stronger association between nonword repetition and vocabulary knowledge. Gathercole et al. (1997) suggested that the ability to repeat nonwords and acquire good vocabulary skills was constrained by the phonological capacity of short term memory, and by long term phonological knowledge.

Several developmental studies have found that phonological encoding and storage skills are involved in learning new words (Gathercole & Baddeley, 1989; 1990). Gathercole and Baddeley (1990) investigated the causal role of phonological memory in children's vocabulary acquisition. Thirty-seven five year old children were divided into high and low ability groups, based on their performance on the nonword repetition task (CNRep). Non-words were used as the criterion measure of phonological memory for two reasons. First, non-words provide a pure measure of phonological memory because they provide no lexical support. Secondly, nonword repetition has been shown to be linked with vocabulary acquisition in young children. Children were also tested on measures of verbal and nonverbal skill.

Each group completed two learning sessions. In each session, the task was to learn the labels assigned to the four toys. There were two sets of plastic toy animals and two sets of labels, names, and nonsense names. At the start of every trial in each session, the experimenter presented a toy to the child and stated the label assigned to the toy. The child was asked to repeat the label. Trials did not begin until the child was able to pronounce the labels of all four toys. In the experimental trials, the experimenter presented the child with the toy, and asked the child what the label of that toy was.

The child was considered to have learned the names if they were able to label the four toys correctly, on two successive trials. The trial was discontinued if the child reached the maximum fifteen trials, even though they had not learned the labels for the toys. In addition, two surprise tests were given to the children 24 hours later to test their ability to retain the labels. The first test required the children to name the toys, when presented to them individually. Secondly, all toys were put on the table at once and the children were asked to identify the names (e.g. "Which one is Michael?"), and told to point to the correct toy.

The overall learning curves revealed that all the children learned more names than nonsense names. Importantly, the low ability children learned fewer labels than the high ability children, and took more trials to learn the labels for both names and the nonsense names than the high ability group. Furthermore, of the children who reached criterion for the nonsense names, the low ability group took an average of two trials longer than the high ability group.

Further analyses were conducted to address the possibility that the low ability group was worse at learning the names of the animals as a result of poor vocabulary and reading skills. These analyses revealed that neither vocabulary nor reading measures contributed to faster learning of the high ability group. In contrast, nonword repetition did show unique association with nonsense name learning. Similar results were found in the analyses investigating the effects of learning speed on real name learning. Lastly, analyses were conducted on the two delayed recall tests. The results showed that the differences between the two groups on the delayed tests were mainly attributable to initial learning differences.

Thus, the high ability group learned the labels of the toys more quickly than the low ability group. Specifically, the high ability group was quicker at learning the nonsense names. This suggests that phonological memory played an important role in vocabulary development. The retention tests showed that differences between the two groups were largely due to differences in initial learning abilities. However, when groups were compared on the trials learned to criterion, the low ability group was worse at matching the toy with this label. This supported the theory that phonological memory contributed to vocabulary development.

Taken together, these studies suggest that children with poor phonological memory skills have difficulty learning novel words. There is a large literature demonstrating the verbal memory difficulties of dyslexic readers. Plausibly, dyslexic children experience difficulty in learning novel names partly as a consequence of poor verbal memory skills. Reasonably, difficulties in novel word learning negatively impact vocabulary development, which in turn has knock-on effects on reading and spelling development.

2.4 Summary

The most widely accepted cognitive deficit of dyslexia is the phonological deficit. There is a substantial amount of evidence to suggest that phonological awareness is important in attaining efficient reading skills (Bradley & Bryant, 1983; 1985). Moreover, there is evidence to suggest that dyslexic children perform worse than chronological age controls and reading age controls, on more difficult measures of phonological awareness such as phoneme deletion. Dyslexic children also show impairments in nonword reading. Importantly, dyslexic children's phonological awareness skills do not develop like those of normal readers (Bruck, 1992; Snowling & Goulandris, 1994). Indeed, even adult dyslexics do not achieve the level of phonological awareness skill of normal readers.

Furthermore, dyslexics have memory span difficulties, comprising digit or letter strings (Jorm, 1983). There is some evidence to suggest that the level of performance on verbal memory tasks is dependent upon the integrity of the underlying phonological representations. Plausibly, memory span and speech rate tasks tap the quality of the phonological representations, which are also used in setting up an efficient reading system. Interestingly, McDougall et al., (1994) showed that speech rate was a more sensitive index of the underlying phonological representations than memory span.

Finally, Gathercole and colleagues have shown that novel word learning is constrained by short term memory processes, and vocabulary knowledge. Interestingly, poor readers learning novel words using a paired associate learning paradigm had more difficulty learning paired associates than normal readers. The poor readers were also worse than normal readers on tests of nonword repetition; a test of verbal short term memory. Plausibly, nonword repetition and novel word learning using the paired associate learning paradigm are both impaired because of poorly specified underlying phonological representations. Arguably, both measures tap phonological representations.

Chapter Three

An Experimental Investigation into the Relationship between Memory Span and Speech Rate

3.1 Overview

This chapter reports two studies investigating the performance of dyslexics, reading age matched controls and chronological age controls on tests of memory span and speech rate. We approached these studies from the phonological deficit hypothesis. Our view is that dyslexics are deficient in their ability to create phonological representations, and these difficulties have knock-on effects for phonological processing skills such as verbal short-term memory. We compared the results of the memory span and speech rate tasks quantitatively, examining memory span and speech rate tasks separately, and in relation to each other. Furthermore, we investigated speech rate errors qualitatively, to compare the pattern of errors for control and dyslexic subjects.

3.2 Introduction

The working memory model has been influential in the study of memory processes (Baddeley & Hitch, 1974). As discussed in Chapter 1, the model comprises three component parts: the central executive, the phonological loop, also referred to as the articulatory loop, and the visuo-spatial sketchpad (see Figure 1.1). The central executive co-ordinates activity within working memory and controls the transmission of incoming information to the phonological loop and the visuo-spatial sketchpad. The phonological loop is specialised for the storage of verbal material. Baddeley (1986) refined the original working memory model, separating the phonological loop into two component processes: the phonological store, and articulatory control processes (see Figure 1.2).

This model is commonly known as a trace decay model (TDM). According to this model, verbal short-term memory is constrained by rehearsal processes and decay time within the phonological loop. The phonological loop is thought to be approximately two seconds in duration. Thus, a person is able to remember only what can be rehearsed within the two second time duration of the loop. Degradation of the sequence occurs when the two second time of the phonological loop is exceeded.

There is a large literature demonstrating the strong relationship between sub-vocal rehearsal processes and verbal short term memory. This has been demonstrated by the occurrence of the word length effect (Baddeley, Thomson, & Buchanan, 1975). Essentially, one can rehearse more short items within two seconds, than longer items. There is also considerable evidence suggesting that dyslexics have shorter memory spans, resulting from "difficulties in utilising the articulatory loop " (Jorm, 1983, p.314) (Spring, 1976; Torgeson & Houck, 1980). Several studies have shown that dyslexic children do not demonstrate the same magnitude of phonological similarity effect as normal readers (Shankweiler et al., 1979). However, this finding has been refuted (Johnson et al., 1987). A parsimonious account of the available evidence is that the magnitude of the phonological similarity effect depends partly on the task demands. Moreover, it may depend on the age of the subjects. Smaller phonological similarity effects were found with a young group of poor readers, but not with older poor readers (Shankweiler et al., 1979; Johnson et al., 1987).

3.3 Experiment One

3.3.1 Introduction

This experiment investigated three main issues. First, memory span and speech rate performance were examined in dyslexic, reading age, and chronological age controls. The factors which were manipulated were lexicality (words and nonwords) and length (short, medium, long). Research into the verbal short-term memory abilities of dyslexics have typically incorporated words as stimuli. The use of nonwords allows for a purer measure of the ability to create phonological representations and rehearse them within the articulatory loop, in the absence of a long term memory contribution. Furthermore, memory span was investigated as a function of speech rate in all three groups. Lastly, errors in the speech rate task were examined qualitatively, to compare the pattern of errors of dyslexic and non-dyslexic children.

In line with previous studies, we expected to find length and lexicality effects in each of the three groups. A common interpretation of length effects in traditional memory span tasks is that they reflect sub-vocal rehearsal processes in the articulatory loop, which in turn affect memory span. The faster a child rehearses items within the two second duration of the articulatory loop, the longer the memory span will be. Conversely, the slower a child's rehearsal processes are, the shorter the memory span will be. Moreover, it can be assumed that the ability to rehearse items in the articulatory loop is dependent upon the quality of the phonological representations that are maintained. Fully established phonological representations are easier to rehearse than degraded phonological representations. Differences between the control groups should arise from developmental differences in the efficiency of the articulatory loop.

Lexicality effects in span tasks are interpreted as reflecting the contribution from long term phonological memory. Typically, older children who have more experience with words, show a greater contribution from long term memory to short term memory processes, than younger children. In contrast, nonwords lack long term memory representation, which is reflected in a decrement in performance on nonwords in memory span and speech rate tasks. Thus, any differences in lexicality between the control groups should result from a greater long term memory contribution experienced by the older control group.

We expected that dyslexics would experience a boost from the familiar phonological sequences of real words, compared to the unfamiliar phonological sequences of the nonword items, resulting from deficient phonological processing skills. Moreover, we expected that dyslexics would experience a benefit from the semantic content of real words. In comparison to the chronological age controls, we expected that dyslexics would perform worse on both word and nonword items, as dyslexics do not perform age appropriately resulting from their phonological deficiencies. Furthermore, we expected that they would have more difficulties than their peers with longer compared to shorter words.

In general, span differences have not emerged between dyslexics and younger reading age controls. However, this may have been because such children rely relatively more on long term memory process in short term memory tasks. It follows that dyslexics may show relative deficits on nonword span, when they are unable to draw on established long term memory resources. This hypothesis leads to the prediction that dyslexics will show larger lexicality effects than younger reading age controls. Furthermore, word span in dyslexics should be less well predicted by speech rate than for reading age controls whose use of articulatory processes can be assumed to be intact. Similarly, we reasoned that dyslexics' and reading age controls' performance would be similar for shorter, one syllable items, because of general developmental advantages for the dyslexics. However, we expected to see a sharp decline with increasing item length, resulting from their poor phonological skills. Thus, the poorest performance was expected in the long nonword condition.

3.3.2 Method

3.3.2.1 Participants

The study involved 11 dyslexic readers, 11 reading age controls, and 11 chronological age controls. Details of the children who participated are shown in Table 3.1. All the participants in the present study came from schools in the north of England and Wales. Dyslexics were matched with a reading age control within six months of their reading age, and a chronological age control, within six months of their chronological age. All the dyslexic children were diagnosed as dyslexic and had been statemented as such (see Appendix K1 for details of dyslexic sample).

Table 3.1

Participant details of dyslexic and normal readers (RA control; CA controls)

Age Group	Age Ranges	
	Chronological ages	Reading ages
Dyslexics		
Mean	15;4	12;1
sd	9.18	16.00
range	14;0-16;5	10;7-14;0
RA controls		
Mean	10.9	12;1
sd	5.96	18.00
range	9;7-11;5	9;5-14;0
CA controls		
Mean	15;3	16;01
sd	5.96	17.43
range	14;5-16;1	13;2-17;0

3.3.2.2 Design and Materials

The Basic Reading subsection of the Word Reading Test (Wechsler, 1993), a test of single word reading was used in the selection of the participants. Following this, the Graded Nonword Reading test (Snowling, Stothard, & McLean, 1996) was administered to the participants using flashcards, with one nonword printed on each card. There were five one syllable practice words, followed by ten one-syllable nonwords, and ten two-syllable nonwords, with a maximum score of twenty. This test was discontinued after six consecutive failures.

The words and nonwords employed in the memory span task were the same as those used by Hulme et al., (1991). Three sets of words of one-, three- and five syllable lengths, as well as three sets of nonwords of one-, two- and three syllable lengths were used (see Appendix A). The memory span task was controlled via a Macintosh computer, using the STM Experimenter program comprising digitised and randomised presentation of items (see Cox, Hulme and Brown, 1992 for details). Furthermore, a Latin square determined the order in which the children did the sets of words and nonwords.

The children were presented with lists of items, presented to them at 1 item per second. They were presented with four lists at each list length. The beginning list length was two, to ensure that all the children could correctly recall all four of the lists. Thereafter, the child was presented lists increasing in length by one item, until they missed two consecutive trials at any list length. Each subject's score was calculated as the longest list length for which all four lists were correctly recalled, plus .25 for each longer list that was correctly recalled.

A speech rate task was administered after the span task (see Appendix A). Item pairs were played for the participants via the computer. The items in the speech rate task were the same as those in the memory span task. There were four pairs of items for each list. The participants were asked to repeat the pair of words ten times, as fast and accurately as possible. Each list was timed with a stop watch, and the four scores for each list of pairs was averaged. The score was converted into a words/second score, which was used as the measure of speech rate.

Finally, two tasks were administered as controls for the motor demands of the speech rate task. A verbal articulatory control task required participants to repeat the syllables [puh], and [guh], twenty times at the fastest rate possible.

3.3.2.3 Procedure

Each child was tested within the school. Reading age controls received three testing sessions, lasting approximately thirty minutes each. Older dyslexics and chronological age matches received one testing session of between 45 minutes and 1 hour. The first session began with the Basic Reading subsection of the Word Reading Test. The Graded Nonword Reading Test was administered second. The tasks in the remaining two sessions were presented in counterbalanced order. All tests were timed.

Each child was instructed to listen to a list, and to repeat the list in the order it was presented. The experimenter carried on until the subject missed two consecutive lists within a block of four lists. Following each memory span list, participants were asked to complete a speech rate task involving repetition of word pairs given to them by the experimenter. If the word pairs were forgotten in the middle of the trial, the experimenter reminded the child after which they were instructed to carry on. All trials were recorded on the DAT for later transcription. Participants were finally asked to complete the remaining two articulatory tasks.

3.3.3 Results

3.3.3.1 Memory Span

Memory span was calculated at each syllable length for words and nonwords. The data for each group are shown in Table 3.2. Collapsing the data across word length showed dyslexics had an average word span of 3.56, and a nonword span of 2.26, with a difference of 1.30. Reading controls had a word span of 2.9, a nonword span of 2.23, with a difference of .67. CA controls had an average word span of 3.73, a nonword span of 2.43, with a difference of 1.33. All three groups showed an advantage for words over nonwords.

Table 3.2

<u>Mean scores on memory span as a function of i) lexicality and ii) length for dyslexics and normal readers (RA controls; CA controls)</u>

	Words			Nonwords		
Groups	short	medium	long	short	medium	long
Dyslexics						
Mean	4.0	3.7	3.0	2.6	2.2	2.0
sd	.43	.53	.53	.50	.47	.40
RA controls						
Mean	3.4	3.1	2.2	2.6	2.3	1.8
sd	.64	.60	.62	.38	.30	.46
CA controls						
Mean	4.1	3.9	3.2	3.1	2.3	1.9
sd	.74	.76	.67	.74	.58	.50

An analysis of variance was carried out on the memory span data with one between subjects factor, Group (dyslexic; RA control; CA control), and two within subjects factors, Lexicality (word; nonword), and Item Length (short; medium; long). This analysis revealed significant main effects of group ($F(2, 30) = 4.00$, $MSe = 4.31$, $p<.05$), lexicality ($F(1, 30) = 288.89$, $MSe = 59.18$, $p<.001$), and length ($F(2, 60) = 107.77$, $MSe = 15.84$, $p<.001$).

Post hoc analyses (Newman Keuls) of group revealed that dyslexics performed comparably to RA and CA controls ($p>.05$). RA controls performed significantly worse than CA controls ($p<.05$). Post hoc analyses of length (Newman Keuls) revealed that short words were remembered better than both medium ($p<.05$) and long items ($p<.05$). Medium length item were also better remembered than long items ($p<.05$).

The significant lexicality effect was modified by a group by lexicality interaction ($F(2, 30) = 9.50$, $MSe=1.95$, $p<.01$). Post hoc analyses (Scheffé Test) of the group x lexicality interaction revealed dyslexics performed significantly better than RA controls ($p<.01$), who were significantly worse than CA controls ($p<.001$) on word items. There were no significant group differences on nonword items.

A significant interaction was also found between lexicality by length ($F(2,60)= 5.36$, $MSe=.86$, $p<.01$). Post hoc analyses (Scheffé Test) of the lexicality by length interaction revealed that short words were significantly better than long words ($p<.001$), but no different than medium words ($p>.05$), which in turn were significantly better than long words ($p<.01$). Short nonwords were significantly better than medium ($p<.01$) and long ($p<.01$) nonwords, which were significantly different from each other ($p<.05$).

3.3.3.2 Speech Rate

Speech rate was calculated for words and nonwords. The data for each group are shown in Table 3.3. Dyslexics obtained a mean speech rate of 1.60 w/s for words and 1.73w/s for nonwords. RA controls obtained a mean of 1.4 w/s for words and 1.60 w/s for nonwords. CA controls obtained a mean of 1.60 w/s for words and 1.66 w/s for nonwords.

Table 3.3

Mean scores on speech rate (items/second) as a function of i) lexicality and ii) length for dyslexics and normal readers (RA controls; CA controls)

		Words			Nonwords		
Groups		1 Syllable	3 Syllable	5 Syllable	1 Syllable	2 Syllable	3 Syllable
Dyslexics							
	Mean	2.1	1.7	1.0	2.4	1.6	1.2
	sd	.49	.29	.16	.54	.30	.16
RA controls							
	Mean	1.9	1.5	.80	2.3	1.4	1.1
	sd	.41	.20	.14	.32	.24	.15
CA controls							
	Mean	2.0	1.7	1.1	2.2	1.5	1.3
	sd	.55	.44	.23	.57	.45	.35

An analysis of variance was carried out on speech rate data with one between subjects factor, Group (dyslexics; RA controls; CA controls) and two within subjects factors, Lexicality (words; nonwords) and Item Length (short; medium; long).

Analyses revealed significant main effects of lexicality ($F(1, 30) = 25.86$, $MSe = .68$, $p < .001$), and length ($F(2,60) = 261.67$, $MSe = 19.47$, $p < .001$). The main effect of group did not reach significance.

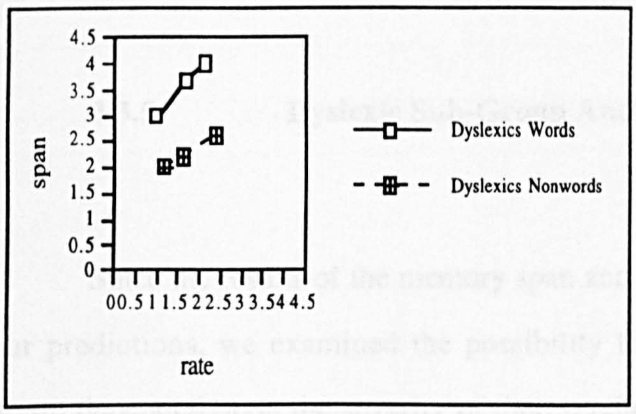
Post hoc analyses (Newman Keuls) of length revealed that short items were better remembered than long items ($p < .05$) and medium items ($p < .05$), which in turn were better remembered than long items ($p < .05$). Furthermore, a significant lexicality by length ($F(2,60) = 29.01$, $MSe = .98$, $p < .001$) interaction was found. Post hoc analyses (Scheffé Test) revealed that the interaction occurred because short words were rehearsed more slowly than short nonwords ($p < .01$). Medium words were significantly faster than medium nonwords ($p < .05$). Long words were again rehearsed more slowly than long nonwords ($p < .01$).

3.3.4 The Relationship Between Memory Span and Speech Rate

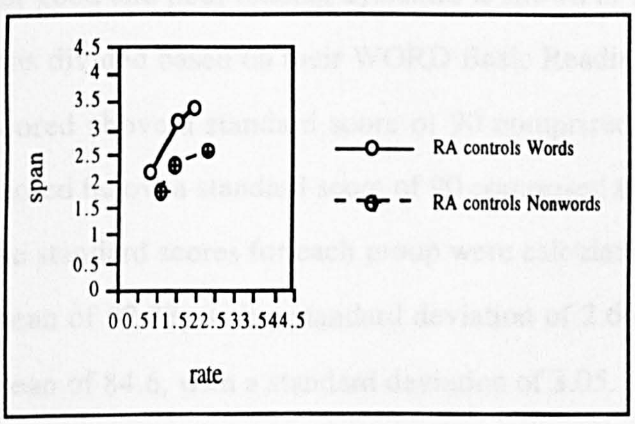
To investigate the long term memory contribution to verbal short term memory, we examined the slope and intercept of the function relating memory span and speech rate for words and nonwords for each group. The relationship between memory span and speech rate for dyslexics, RA controls and CA controls is depicted in Figures 3.1 (a-c). We were particularly interested in the intercept, as it can be considered to represent the contribution of long term memory to short term memory processes.

Figure 3.1 Graph showing memory span as a function of speech rate for words (five, three and one syllable, from left to right) and nonwords (three, two and one syllable, from left to right), for dyslexics (a.), RA controls (b.), and CA controls (c.), respectively.

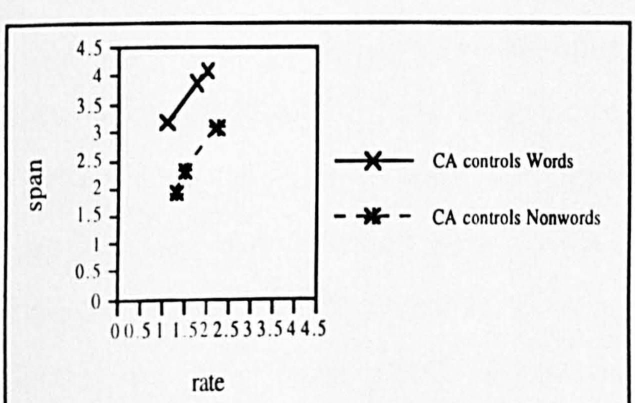
a.



b.



c.



The intercepts for word items were 2.10, 1.34, and 2.10 for dyslexics, RA controls and CA controls, respectively. The intercepts for nonword items were 1.4, 1.29, and .30 for dyslexics, RA controls and CA controls, respectively. Thus, the word items benefited more from long term memory representations, than nonword items.

3.3.5 Dyslexic Sub-Group Analysis

Since the results of the memory span and speech rate analyses did not confirm our predictions, we examined the possibility that the performance of the dyslexic group depended upon the severity of their reading problem. The memory span data for good and poor reading dyslexics is shown in Table 3.4. The group of 11 dyslexics was divided based on their WORD Basic Reading subtest standard score. Those who scored above a standard score of 90 comprised the high ability group. Those who scored below a standard score of 90 comprised the lower ability group. The means of the standard scores for each group were calculated. The high ability group obtained a mean of 92.33, with a standard deviation of 2.66. The lower ability group obtained a mean of 84.6, with a standard deviation of 3.05.

Table 3.4

Mean scores on memory span as a function of i) lexicality and ii) length for dyslexic sub-groups

	Words			Nonwords		
Groups	short	medium	long	short	medium	long
High Ability Dyslexics (N=6)						
Mean	4.21	3.75	3.00	2.79	2.21	2.16
sd	.43	.65	.65	.53	.53	.20
Low Ability Dyslexics (N=5)						
Mean	3.65	3.65	2.95	2.45	2.1	1.75
sd	.14	.42	.41	.41	.42	47

Although the number of subjects was small, analyses of variance were carried out on the memory span and speech rate data. An analysis of variance was carried out on the memory span data with one between subjects factor, Group (high ability; low ability) and two within subjects factors, Lexicality (words; nonwords) and Length (short; medium; long). This analysis revealed main effects of lexicality ($F(1,9)=120.31$, $MSe=.22$, $p<.001$) and length ($F(2,18)= 20.92$, $MSe=.17$, $p<.001$). Importantly, the main effect of group did not reach significance. Post hoc analyses (Newman Keuls) of length showed that short items were better remembered than long ($p<.05$) and medium items ($p<.05$), which in turn were better remembered than long items ($p<.05$).

There was also a significant interaction between lexicality by length ($F(2,18)=9.46$, $MSe=.03$, $p<.05$). Post hoc analyses (Scheffé Test) of the lexicality by length interaction revealed memory span was significantly poorer for long than medium words, which did not differ from short words ($p>.05$). For nonwords, span was significantly poorer for medium ($p<.05$) and long items ($p<.01$) than short items, but these did not differ from each other ($p>.05$).

Table 3.5

Mean scores on speech rate (items/second) as a function of i) lexicality and ii) length for dyslexic sub-groups

	Words			Nonwords		
Groups	short	medium	long	short	medium	long
High Ability Dyslexics (N=6)						
Mean	1.82	1.70	1.04	2.13	1.48	1.21
sd	.47	.40	.24	.59	.35	.21
Low Ability Dyslexics (N=5)						
Mean	2.48	1.73	1.05	2.65	1.65	1.24
sd	.21	.13	.12	.33	.23	.08

An analysis of variance was carried out on the speech rate data with one between subjects factor, Group (high ability; low ability) and two within subjects factors, Lexicality (words; nonwords) and Length (short; medium; long). This analysis revealed main effects of lexicality ($F(1,9)=7.78$, $MSe=.02$, $p<.05$) and length $F(2,18)=134.59$, $MSe=.05$, $p<.001$). The main effect of group did not reach significance. Post hoc analyses (Newman Keuls) of length revealed that shorter items were repeated more quickly than long ($p<.05$) and medium length items ($p<.05$), which in turn were repeated more quickly than longer items ($p<.05$).

There was a significant group by length interaction ($F(2,18)=9.66$, $MSe=.05$, $p<.01$). Post hoc analyses (Scheffé Test) of the group by length interaction revealed that good dyslexic readers were different from poor dyslexic readers on short items ($p<.01$). However, the groups were no different on medium ($p>.05$) or long ($p>.05$) items.

There was also a significant lexicality by length interaction ($F(2,18)=9.47$, $MSe=.24$, $p<.01$). Post hoc analyses (Scheffé Test) revealed that the interaction occurred because short words did not differ from short nonwords ($p>.05$). Similarly, medium words were no different from medium nonwords ($p>.05$), and long words were no different from long nonwords ($p>.05$).

3.3.6 Summary

Thus, the memory span and speech rate data were not entirely consistent with our hypotheses. Although lexicality and length effects were found for all groups, the group differences were not in the predicted direction. Dyslexics performed comparably to CA and RA controls on memory span. However, there were developmental differences in the expected directions. More surprisingly, there were no group differences on nonword items in the memory span task. The dyslexic sub-group analysis suggests that the lack of group differences was not due to heterogeneous performance in the dyslexics group. Finally, the speech rate data revealed that there were no group differences overall. Therefore, we conducted a qualitative error analysis to further investigate the unexpected pattern of findings.

3.3.7 Speech Rate Error Analysis

The corpus of errors on the speech rate task was examined to determine the types of speech error made by each group of participants. Error categories were established, following scrutiny of the transcriptions. Examples of all the error types is shown in Table 3.6

Table 3.6

Error categories for word and nonword items in the speech rate task

Error Type	Error Description	Example
Syllable Error	syllable is added or deleted from target item	aluminium-/aləmInəm/ bepavit-/bəvɛtəbIt/
Amalgamation Error	two separate items become re-ordered to create a new item	scroll/switch /skrItʃ/ gossikos/jozadum-/dʒɒzikəm/
Phoneme Error	phoneme is added, deleted, or substituted from target item	switch - /skwItʃ/ ballem- /bælɛb/
Programming Error	stutters, or hesitations, in which the incorrect item is eventually vocalised	botany- /bɒ...bɒtəmlə/ gossikos-/gɒ...kɒsləkɒs/
Other Errors	errors which could not be classified otherwise	scroll- /zIl/ zegglepim- /dɛkoupɛp/

The distribution of errors committed by dyslexics, RA and CA controls for words in the speech rate task, collapsed across length is presented in Table 3.7.[1] A one-way analysis of variance was carried out on the total number of errors committed, with between subjects factor, Group (dyslexics; RA controls; CA controls). This analysis revealed a main effect of group ($F(2,21)=6.12$, $MSe=16.08$, $p<.01$). Post hoc analyses (Newman Keuls) showed that dyslexics committed significantly more errors than CA controls ($p<.05$), but did not differ from RA controls. RA controls also committed significantly more errors than CA controls ($p<.05$).

[1] The speech rate error analysis for words and nonwords was carried out on only 24 of the 33 participants due to equipment failure. There were eight participants in each group.

Furthermore, dyslexics appear to have made a greater proportion of syllable errors than CA controls, although comparable to RA controls. This suggests that dyslexics had difficulty at a basic level of phonological analysis. Unexpectedly, CA controls committed more amalagamation errors than the other two groups. Finally, the three groups appear to have committed approximately equal proportions of errors in the remaining error categories.

Table 3.7

Proportion of errors for word items across lengths in the speech rate task for dyslexics, and normal readers (RA controls; CA controls)

	Group		
	Dyslexics	RA controls	CA controls
Errors	N=265	N=284	N=121
Syllable Errors	.19	.22	.09
Phoneme Errors	.44	.39	.35
Amalgamations	.26	.29	.49
Programming Errors	.08	.07	.07
Other	.03	.03	.00

The distribution of errors made when repeating nonwords in the speech rate task, collapsed across length is shown in Table 3.8. A one-way analysis of variance was carried out on the total number of errors committed with between subjects factor, Group (dyslexics; RA controls; CA controls). This analysis showed a main effect of group ($F(2,21)=8.60$, $MSe=491.58$, $p>.01$). Post hoc analyses (Newman Keuls) showed that dyslexics committed significantly more errors, than CA controls ($p<.01$), but did not differ from RA controls (p>.05), who in turn committed significantly more errors than CA controls (p<.01).

Furthermore, dyslexics made a greater proportion of syllable errors than both RA and CA controls. Thus, in the nonword speech rate task, dyslexics had greater difficulty than younger RA controls at a basic level of phonological analysis. Consistent with the word speech rate data, the three groups made approximately equal proportions of errors in the other error categories.

Table 3.8

Proportion of errors for nonword items in the speech rate task for dyslexics and normal readers (RA controls; CA controls)

	Group		
	Dyslexics	RA controls	CA controls
Errors	N=801	N=814	N=489
Syllable Errors	.06	.01	.01
Phoneme Errors	.88	.94	.88
Amalgamations	.00	.00	.00
Programming Errors	.03	.03	.10
Other	.03	.02	.01

3.3.8 Control Tasks

The means and standard deviations for the articulatory control tasks involving the repetition of speech sounds and of articulatory movements, examined as the number of gestures per second, are shown in Table 3.9. These data indicate that the articulatory speed of reading age controls was slower than that of dyslexics and chronological age controls in all three tasks. The chronological age controls appear faster than the dyslexics do. However, an analysis of variance indicated that none of the group differences were significant ($F(2,30)=1.18$, $p>.05$). The group by task interaction did not reach significance ($F(4,60)=.14$, $p>.05$).

Table 3.9

<u>Mean scores on articulatory control tasks for dyslexics and normal readers (RA controls; CA controls)</u>

	Number of Articulatory Gestures per Second	
Groups	pə	gə
Dyslexics		
Mean	4.51	4.25
sd	1.60	1.27
RA controls		
Mean	3.98	3.95
sd	1.08	.92
CA controls		
Mean	4.82	4.51
sd	1.11	.97

3.3.9 Discussion

This experiment replicated the lexicality, and word length effects characteristic of STM performance. Memory span performance was sensitive to phonological variables and the availability of long term memory processes. Furthermore, we replicated the finding of a strong relationship between memory span and speech rate. However, there were three unexpected findings in the present experiment. First, there were no differences between dyslexics and chronological age controls for memory span. Secondly, there were no developmental differences found in memory span for nonwords. Lastly, we found no group differences in speech rate. The failure to find these usually robust findings lead us to question certain aspects of the paradigm used in the present study.

The sensitivity of the scoring in the memory span and speech rate tasks may have accounted for the lack of group differences. Unfortunately, the span data was not recorded, so we were unable to see if stricter scoring would have revealed group differences in the expected directions. However, the speech rate data was subjected to error analyses. Interestingly, the qualitative error analysis revealed a different pattern of results to that of the quantitative analyses. Dyslexics committed approximately twice the number of word and nonword errors as chronological age controls. Thus, perhaps the quantitative speech rate data is an overestimation of the true speech rate of the participants, suggesting a speed-accuracy trade off. Furthermore, there were no significant group differences between dyslexics and CA controls on the articulatory gesture tasks. This suggests that dyslexics did not have any articulatory difficulties which could have explained the differences in error rates.

Moreover, one could speculate that memory span is determined more by long term memory processes than by rehearsal processes, for dyslexic readers. We favour the view that dyslexics compensated in their performance for word items, using long term memory resources. Plausibly, this may have occurred through redintegration processes (Brown & Hulme 1995). Redintegration can be defined as a process by which "lexical knowledge is used to fill in decayed phonological representations in the phonological store" (Gathercole et al., 1997, p.976). Thus, the ability to perform effectively in a verbal short-term memory task, may be constrained by more than the efficiency of articulatory loop processes. Long term memory representations may aid the processes of redintegration as the decaying phonological representations can be filled quickly by familiar phonological sequences. This process would be less efficient with nonword items, as long term memory representations are not readily available for nonword items.

Thus, Experiment 2 was designed as a replication and extension of the present experiment. We aimed to replicate the word length and lexicality effects in memory span and speech rate tasks in dyslexic readers, reading age controls and chronological age controls. Furthermore, the experiment was extended to include items varying in their phonological neighbourhoods. It was predicted that this variable would be particularly sensitive to the phonological deficit in the dyslexic readers, revealing group differences which we did not find in Experiment 1. Furthermore, morphological structure of the three syllable stimuli was manipulated. This variable was included to investigate the contribution of semantic information provided by morphological information, among the three groups. It was expected that dyslexics' ability to extract semantic information would be intact, compared to their inability to extract and utilise phonological information.

3.4 Experiment Two

3.4.1 Introduction

The one syllable items comprised words and nonwords with high and low phonological neighbourhood items. Consistent with a redintegration hypothesis, it was expected that the inclusion of items from high phonological neighbourhoods in the memory span task would boost the recall and rehearsal of the target items. Items with high phonological neighbourhoods comprise phonemes common to a large number of items. Thus, the long term memory representations for these phonemes are salient, and are accessible to fill in decaying phonemes. Conversely, items with low phonological neighbourhoods comprise phonemes common to fewer items. The long term representations for these phonemes are less salient, and are not accessed as readily when required to fill in decaying phonemes.

Since available norms do not allow for the examination of the phonological neighbourhoods of multi-syllabic items, the effects of derivational morphemes were examined, for the three syllable items. Morphemes are written in the same way, irrespective of the phonological variability of a word. For instance, /-s/ at the end of a word always refers to the plural of the word. Thus, the pervasiveness of the morphemic principle allows a reader to understand words he/she may not have encountered previously.

Elbro (1990) investigated the use of morphemic principles in reading and writing tasks, among dyslexics and younger reading age controls. The general findings of the experiments suggested that dyslexics relied heavily on the morphemic constraints of words compared to younger reading age controls. Moreover, morphemic knowledge accounted for differences between normal and dyslexics which were not accounted for by differences in phonological knowledge. This suggests that dyslexics used morphological knowledge as a compensatory strategy.

3.4.2 Method

3.4.2.1 Participants

The study involved 15 dyslexic readers, 15 reading age matched controls and 15 chronological age matched controls. Details of the participants are shown in Table 3.10. All the dyslexic children had been diagnosed as dyslexic, and had been statemented. Furthermore, one of the children included in this study had also participated in Experiment 1 (see Appendix K 2 for details of the dyslexic sample).

Table 3.10

Participant details of dyslexics, and normal readers (RA controls; CA controls)

Group		Chronological age (in months)	Reading ages (in months)
Dyslexics			
	Mean	14;6	9;8
	sd	8.92	23.71
	range	13;6-16;0	6;7-13;2
RA controls			
	Mean	9;3	9;6
	sd	20.57	20.93
	range	7;0-12;6	7;2-12;2
CA controls			
	Mean	14;6	15;0
	sd	9.64	20.84
	range	13;7-16;0	12;7-17;0

Each dyslexic was matched with a reading age control within six months of their reading age, and a chronological age control, within six months of their chronological age. All participants were from York primary and secondary schools. All participants were administered the WORD Basic Reading Subtest, a test of single word reading. A reading age was calculated from the raw scores.

3.4.2.2 Design and Materials

Four lists were prepared to assess the influence of phonological neighbourhood and lexicality (see Appendix B). Sixteen one syllable items were selected from the Phonological Neighbour Program (Roodenrys, unpublished), which contains a word base selected from the Oxford Psycholinguistic database (Quinlan, 1992). Half of the one syllable items were selected from high phonological neighbourhood words (e.g. job, cold) and half from low phonological neighbourhood words (e.g. land, jazz). The items were matched for frequency. Phonological neighbourhoods were defined as those items which deviated from the target word by one phoneme. One syllable nonwords were constructed from real words through consonant substitution in initial or medial positions. Vowels were never substituted. Nonwords were grouped into high phonological neighbourhood nonwords (e.g. pob, jold) and low-phonological neighbourhood nonwords (e.g. gand, vazz).

To assess the influence of the lexicality and morphological composition of items, a word span task comprising four lists was prepared (see Appendix C). The list comprised sixteen three syllable items matched with the one syllable items for frequency. Half of the three syllable word lists contained derivational affixes (e.g. difference, national) and half did not (e.g. soviet, capital). Three syllable nonwords were constructed from real words through consonant substitution in the initial position of the first, or third syllable. Vowels were never substituted. Nonwords were grouped into derivationally affixed (e.g. sifference, vasious) and non-derivationally affixed nonwords (e.g. noviet, canital).

The trials were counterbalanced across subjects. Moreover, lists of words and nonwords were randomised automatically by STM Experimenter program (Cox, Hulme & Brown, 1992). Each list was presented in blocks of four, with a beginning length of two items, and a maximum length of eight items. The test was discontinued when the subject missed two consecutive trials in any given block. Each participant's score was calculated by adding .25 for each correct list, to the maximum list length at which participants could correctly recall all four lists within a block. The session was recorded via a Digital Audio Tape recorder (DAT).

Owing to limitations of available sets of words varying in phonological neighbourhood, it was only possible to vary this factor within the one-syllable item condition. Thus, the present experiment had an imperfectly balanced design. As an alternative, morphology was varied within three-syllable items. However, by controlling for frequency of the one and three syllable word items, it was possible to assess the effect of length and lexicality on span by collapsing across item-type.

A speech rate task was administered following each list in the memory span task (see Appendix B and Appendix C). Half of the items in the word and nonword lists were one syllable in length. The other half consisted of three syllables items. On each trial of the speech rate task, the participant articulated a pair of items from the memory span task at the fastest, most accurate rate possible. Each pair of items was timed with a stopwatch and recorded via a Digital Audio recorder (DAT). The total time taken to complete all four pairs was converted into items/second and used as a measure of speech rate.

3.4.2.3 Procedure

Participants was tested within their school. Reading age controls received two testing sessions, lasting approximately thirty minutes each. Practical constraints rendered it necessary to assess dyslexics and chronological age matches in one testing session of 45 minutes to 1 hour.

Each participant was first administered the WORD Test of Basic Reading. The memory span test was administered next, using a Macintosh Powerbook computer with headphones, and a Digital Audio Tape recorder (DAT) with microphone for recording purposes. Each child was instructed to listen to the items in each list, and to repeat the list of items in the order that they were spoken via the computer.

Following each span list, participants were asked to complete a speech rate task involving repetitions of item pairs. The word pairs consisted of words used in the preceding memory span list. If the pairs of items were forgotten mid trial, the trial was aborted. The experimenter replayed the items, and a new trial was started. A total of ten repetitions was required.

3.4.3 Results

The data from the dyslexics, RA and CA controls was examined in a series of analyses of variance. We first examined memory span performance, collapsed across conditions of phonological neighbourhood and morphological affix. Following this, we examined the effects of phonological neighbourhood and morphological affix in separate analyses. Speech rate performance, and its relationship to memory span was examined next. This was followed by a close examination of the errors committed during the speech rate task.

3.4.3.1 Memory Span

To assess the effect of syllable length and lexicality on memory span, the data from dyslexics, reading age controls and chronological age controls were initially collapsed across item type. These data are shown in Table 3.11.

Table 3.11

Mean scores for memory span as a function of i) lexicality and ii) item length for dyslexics and normal readers (RA controls; CA controls)

Groups	Words		Nonwords	
	1 syllable	3 syllable	1 syllable	3 syllable
Dyslexics				
Mean	3.58	3.00	2.28	1.65
sd	.73	.49	.50	.39
RA controls				
Mean	3.37	2.78	2.1	1.50
sd	.77	.66	.50	.34
CA controls				
Mean	4.09	3.68	2.62	1.95
sd	1.04	.68	.65	.54

An analysis of variance was conducted with one between subjects factor, Group (dyslexics; RA controls; CA controls), and two within subjects factors Lexicality (word; nonword) and Item Length (one syllable; three syllable). This analysis revealed main effects of group ($F(2, 42) = 10.39$, $MSe=6.27$, $p<.001$), length ($F(1, 42) = 51.42$, $MSe=18.34$, $p<.001$), and lexicality ($F(1, 42) = 366.09$, $MSe=71.51$, $p<.001$). There were no significant interactions.

Post hoc analyses (Newman Keuls) of group revealed dyslexics had significantly poorer memory spans than CA controls ($p<.05$), and RA controls were significantly worse than CA controls ($p<.05$). The difference between RA controls and dyslexics did not reach significance.

3.4.3.2 Memory Span for High and Low Phonological Neighbourhood Items

To investigate the influence of phonological neighbourhoods on memory span, the data for one syllable words and nonwords were analysed. The data are shown in Table 3.12.

Table 3.12

Mean scores for memory span as a function of i) lexicality and ii) phonological neighbourhoods for dyslexics and normal readers (RA controls; CA controls)

		Words		Nonwords	
Groups		High	Low	High	Low
Dyslexics					
	Mean	3.8	3.36	2.43	2.13
	sd	.56	.89	.52	.47
RA controls					
	Mean	3.66	3.08	2.40	1.80
	sd	.74	.79	.46	.54
CA controls					
	Mean	4.28	3.91	2.91	2.33
	sd	1.0	1.09	.66	.64

An analysis of variance was conducted using one between subjects factor, Group (dyslexics; RA controls; CA controls) and two within subjects factors, Neighbourhood (high phonological neighbourhood; low phonological neighbourhood) and Lexicality (word; nonword). This analysis revealed main effects of group ($F(2,42)= 7.63$, $MSe=6.13$, $p<.001$), lexicality ($F(1,42)=199.25$, $MSe=82.01$, $p<.001$) and neighbourhood ($F(1, 42) = 24.13$, $MSe=10.27$, $p<.001$).

Post hoc analyses (Newman Keuls) of group revealed dyslexics were significantly worse than CA controls ($p<.05$), and RA controls were significantly worse than CA controls ($p<.05$). There was a non-significant difference between RA controls and dyslexics ($p>.05$).

3.4.3.3 Memory Span for Derivationally and Non-Derivationally Affixed Items

The means and standard deviations were calculated for each group, investigating derivational and non-derivational affixes. The data is shown in Table 3.13. An analysis of variance was conducted using one between subjects factor, Group (dyslexics; RA controls; CA controls) and two within subjects factors, Type (derivationally affixed; non-derivationally affixed) and Lexicality (word; nonword). The analyses revealed main effects of group ($F(2,42)=10.09$, $MSe=7.28$, $p<.001$), lexicality ($F(1,42)= 524.15$, $MSe=94.6$, $p<.001$) and morphological affix ($F(1,42)=14.89$, $MSe=1.70$, $p<.001$).

Table 3.13

Mean scores for memory span as a function of i) lexicality and ii) morphological affix for dyslexics and normal readers (RA controls; CA controls)

	Words		Nonwords	
Groups	Affixed	Non-Affixed	Affixed	Non-Affixed
Dyslexics				
Mean	3.08	2.93	1.80	1.51
sd	.52	.46	.42	.35
RA controls				
Mean	2.86	2.70	1.56	1.45
sd	.62	.70	.33	.35
CA controls				
Mean	3.78	3.58	2.08	1.83
sd	.74	.61	.58	.51

Post hoc analyses (Newman Keuls) of group revealed dyslexics were significantly worse than CA controls ($p<.05$), RA controls were significantly worse than CA controls ($p<.05$). Differences between dyslexics and RA controls did not reach significance ($p>.05$).

There was an interaction found for group by lexicality ($F(2,42)=4.83$, $MSe=.87$, $p<.05$). Post hoc analyses (Scheffé Test) revealed that dyslexics performed significantly worse than CA controls for word items ($p<.001$), as did RA controls ($p<.001$). There were no significant differences between dyslexics and RA controls for word items ($p>.05$). Moreover, there were no significant differences between dyslexics and RA controls ($p>.05$), or dyslexics and CA controls ($p>.05$), for nonword items. However, CA controls performed significantly better than RA controls for nonword items ($p<.05$).

3.4.4 Speech Rate

The performance of dyslexic readers, RA controls and CA controls on the speech rate tasks varying in lexicality and length is shown in Table 3.14.

Table 3.14

Mean scores for speech rate (items/second) as a function of i) lexicality and ii) item length for dyslexics and normal readers (RA controls; CA controls)

Groups	Words		Nonwords	
	1 syllable	3 syllable	1 syllable	3 syllable
Dyslexics				
Mean	2.38	1.73	2.34	1.5
sd	.65	.43	.59	.39
RA controls				
Mean	2.24	1.44	2.08	1.27
sd	.66	.32	.63	.31
CA controls				
Mean	2.69	1.8	2.6	1.50
sd	.77	.44	.71	.34

Analyses of variance were conducted using one between subjects factor, Group (dyslexics; RA controls; CA controls) and two within subjects factors, Lexicality (word; nonword) and Length (one syllable; three syllable) as factors. These analyses revealed main effects of length ($F(1,42) = 225.18$, MSe=.14, $p<.001$), lexicality ($F(1,42)=38.70$, MSe=.03, $p<.001$) and an interaction between the two ($F(1,42) = 8.01$, MSe=.03, $p<.01$). The main effect of group did not reach significance.

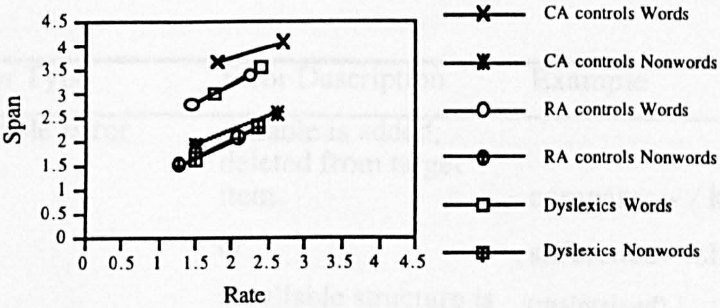
Post hoc analyses (Scheffé Test) of the length by lexicality interaction revealed that one syllable words were significantly better than medium length words ($p<.05$). Short nonwords were significantly better than medium nonwords ($p<.01$).

3.4.5 The Relationship between Memory Span and Speech Rate

The relationship between memory span and speech rate for one and three syllable words and nonwords for dyslexics, reading age controls and chronological age controls is depicted in Figure 3.2. The data suggests that there was a strong relationship between memory span and speech rate in all three groups, as indicated by the similar slopes.

We were particularly interested in the intercepts of the linear function between memory span and speech rate, as they represent the contribution from long term memory. The intercepts for words were 1.46, 1.72, and 2.85 for dyslexics, RA controls and CA controls, respectively. The intercepts for nonwords were .53, .56, and 1.04, for dyslexics, RA controls and CA controls, respectively. The higher intercepts were for words compared to nonwords indicates the benefit from long term memory representations for word items.

Figure 3.2 Graph showing memory span as a function of speech rate for dyslexics, RA controls, and CA controls for words and nonwords (three and one syllables, from left to right).



3.4.6 Speech Rate Errors

The corpus of errors on the speech rate task was examined to determine the types of speech error made by each group of participants. Error categories were established, following scrutiny of the transcriptions. Examples of all the errors types is shown in Table 3.15.

Table 3.15

Error categories for word and nonword items in the speech rate task.

Error Type	Error Description	Example
Syllable Error	syllable is added, deleted from target item	company - /kəmpi/
	or	sifference - /sIfInIns/
	if syllable structure is maintained or not maintained	(maintained)
Amalgamations	two separate items become re-ordered to create a new item	game/test - /tɛm/ noviet/lompani - /nɒməni/
Phoneme Error	phoneme is added, deleted, or substituted from the target item ; lexicalizations, multiple phoneme errors	youth - /jus/ phymical - /fInIkəl/
Programming Error	stutters, or hesitations, in which the incorrect item is eventually vocalised	youth - /ju†...jus/ lompany - /nə...ləmpədi/
Other Errors	errors which could not be classified otherwise (e.g. word words; mumbles)	natural - /naʃənəl/ pommible- /abItʃul/

The distribution of errors made when repeating the words in the speech rate task, collapsed across length is presented in Table 3.16.

Table 3.16

Proportion of errors for word items in the speech rate task for dyslexics and normal readers (RA controls; CA controls)

	Group		
Errors	Dyslexics N=250	RA controls N=257	CA controls N=79
Syllable Errors	.14	.21	.04
Phoneme Errors	.55	.57	.66
Amalgamations	.05	.02	.01
Other	.22	.16	.25
Programming Errors	.04	.04	.04

A one-way analysis of variance was conducted on the total number of errors, with between subjects factor, Group (dyslexics; RA controls; CA controls). The main effect of group did not reach significance. As can be seen from Table 3.16, dyslexics made a greater proportion of syllable errors than CA controls, although comparable to RA controls. The distribution of the remaining error types was similar for the three groups. The pattern of results is consistent with the results of Experiment 1.

The distribution of errors made when repeating the words in the speech rate task, collapsed across length is presented in Table 3.17.

Table 3.17

Proportion of errors for nonword items in the speech rate task for dyslexics and normal readers (RA controls; CA controls)

	Group		
	Dyslexics	RA controls	CA controls
Errors	N=1301	N=1341	N=790
Syllable Errors	.33	.30	.30
Phoneme Errors	.48	.59	.49
Amalgamations	.14	.03	.15
Other	.03	.05	.00
Programming Errors	.02	.03	.06

A one-way analysis of variance was carried out on the total number of errors, with between subjects factor, Group (dyslexics; RA controls; CA controls). We found a main effect of group for the total number of errors ($F(2,42)=4.27$, $MSe=1.47$, $p<.05$). Post hoc analyses (Newman Keuls) showed that dyslexics committed significantly more errors overall than CA controls ($p<.05$), but did not differ from RA controls. RA controls committed significantly more errors than CA controls ($p<.05$). Furthermore, the distribution of errors types was similar for the three groups.

3.4.7 Discussion

The memory span findings from Experiment 1 were clarified in the present experiment. Main effects were found for group, indicating that dyslexics performed worse than chronological age controls. However, contrary to expectations, dyslexics performed comparably to younger reading age controls for words as well as nonwords, suggesting a developmental delay. Lexicality and length effects were also replicated in memory span and speech rate tasks (Hulme et al., 1995; Hulme et al., 1984). Unexpectedly, no group differences were found in the speech rate task.

The data from the phonological neighbourhood task revealed a significant effect of neighbourhood. High neighbourhood items boosted memory span performance, compared to low neighbourhood items. Contrary to our predictions, dyslexics were not more sensitive to phonological neighbourhood effects than control subjects. This result suggests that the dyslexics' phonological lexicon is organised similarly to that of normal readers. However, although the organisation of dyslexics' phonological lexicon appears to be 'normal', for simple one syllable items, the current task may not have been sensitive enough to tap the quality of the phonological representations in the lexicon. Plausibly, the quality of dyslexics' lexicon may be more degraded than normal readers' lexicons, especially for longer items.

The data from the derivational affix data revealed a significant effect of affix. Thus, the presence of derivationally affixed items boosted memory span performance, compared to items which were not affixed. As discussed, derivational affixes are semantically transparent. The findings in the present experiment suggest that readers are sensitive to the benefit of phonological *and* semantic information in a verbal short term memory task. However, contrary to expectations, the interaction between group and lexicality revealed that dyslexics were less influenced by morphological information for words than nonwords, compared to chronological age controls.

The speech rate data were subjected to error analyses as in Experiment 1. Interestingly, the qualitative error analysis revealed a different pattern of results to that of the quantitative analyses. Dyslexics committed approximately twice the number of word and nonword errors as chronological age controls, although differences between groups for word items did not reach significance. Nonetheless, this finding supports the view that the quantitative speech rate data provide an overestimation of the true speech rate of the participants.

3.4.8 Summary and Conclusions

Taken together, the results of Experiments 1 and 2 confirm previous findings in the literature of verbal STM impairments in dyslexic children, with the performance levels of the dyslexic children falling in line with reading age rather than chronological age controls. However, the memory span performance of dyslexic readers was sensitive to the same factors as normal readers, namely it was influenced by length, lexicality, phonological neighbourhood, and by the morphological composition of the items. These findings indicate that the development of verbal memory is delayed but not atypical in dyslexic readers. The two experiments also revealed that dyslexic readers have more difficulty with speech rate tasks, committing more errors than age-matched controls. These results can be taken as indicating that dyslexic readers can only maintain the phonological form of a word (or a nonword) to be articulated as well as younger RA controls.

Overall, the findings are consistent with the phonological deficit hypothesis of dyslexia. According to this hypothesis, phonological representations are poorly specified in dyslexic readers. This constrains their verbal memory and speech rate performance to the level of younger RA controls. The hypothesis also predicts that dyslexic readers will have difficulty in a range of other phonological tasks including learning to associate visual stimuli with a novel phonological forms.

Chapter Four

An Experimental Investigation into the Verbal Learning Skills of Dyslexic and Normal Reading Children

4.1 Overview

The present study investigated differences between dyslexic and normal reading children in their ability to learn visual-verbal paired associates. Both quantitative and qualitative error analyses were carried out with the aim of replicating findings demonstrating that dyslexics were poorer than normal readers on a task involving learning associations between visual stimuli and phonological labels (Wimmer et al., 1997). This study was a precursor to the remainder of the experimental work, which examines the relationship between paired associate learning, phonological awareness and reading among dyslexics, reading age controls and chronological age controls.

4.2 Experiment 3

4.2.1 Introduction

Contrary to expectations of a selective deficit in memory for nonwords, the results of Experiments 1 and 2 suggest that dyslexics were delayed in the development of their memory for words and nonwords, compared to younger reading age controls. There are two possible explanations for this finding. First, the slow phonological development of dyslexics could have resulted in the slow development of verbal short term memory. Alternatively, verbal short term memory may have been constrained by poor reading and spelling development, via the reciprocal relationship between reading, spelling, and phonological processing. Indeed, McDougall et al., (1994) found evidence to suggest that the relationship between reading was mediated by speech rate. Plausibly, dyslexics might show greater deficits in tasks more directly related to reading. In addition, to their well-established deficits in phonological awareness, recent research suggests another candidate process might be paired associate learning (Vellutino et al., 1995; Wimmer et al., 1997).

Thus, our aim was to investigate the performance of dyslexic readers, reading age, and chronological age controls on a test of paired associate learning. First, we aimed to replicate previous findings of group difference between good and poor readers (Vellutino et al., 1995; Wimmer et al., 1997). Importantly, we expected to find differences between dyslexics, and reading age matched controls, consistent with the phonological deficit hypothesis.

Vellutino et al., (1975) were among the first researchers to specify that dyslexics had difficulties with visual-verbal paired associates compared to normal performance on visual-visual paired associate learning. Vellutino et al., conducted a large scale study with fifth and sixth grade good and poor readers. The children were tested on three different paired associate pairs, involving visual, verbal and nonverbal auditory stimuli. Briefly, the results showed that poor readers were only poorer when required to learn paired associate in which visual stimuli were paired with CVC trigrams.

More recently, Vellutino et al., (1995) and Wimmer, Mayringer, & Landerl (1997) conducted studies investigating dyslexic and normal readers performance on paired associate learning tasks. Vellutino et al., (1995) conducted a series of experiments investigating the semantic and phonological coding abilities of good and poor readers. Importantly, the results of their study showed that good readers performed significantly better than poor readers overall. The second experiment included a test of visual recognition, which showed that good and poor readers were no different from each other. Thus, Vellutino et al. suggested that visual-verbal learning was partially determined by the ability to store the verbal component in working memory. Indeed, the results of Experiment 2 suggest that dyslexics have poorer verbal memory than normal readers.

Wimmer et al., (1997) conducted a study investigating differences in paired associate learning in dyslexic and normal readers. The results of the learning task revealed that dyslexics took twice as long to reach the learning criterion as controls. Moreover, many dyslexics were unable to learn the names to criterion. Thus, the available evidence converges on the finding that dyslexics experience great difficulties in paired associate learning involving a verbal component, compared to normal readers.

4.2.2 Methods

4.2.2.1 Participants

The study involved 15 dyslexic readers, 15 reading age matched controls and 15 chronological age matched controls. Details of all the participants are shown in Table 4.1. Every dyslexic children had been diagnosed as dyslexic and was statemented as such. All the dyslexic children from Experiment 2 participated in the present Experiment (see Appendix K3 for details of dyslexic sample). One child had participated in all three Experiments thus far.

Table 4.1

Participant details of dyslexics and normal readers (RA controls: CA controls)

Group	Chronological age	Reading age
Dyslexics		
Mean	14;6	9;8
sd	8.92	23.71
range	13;8-15;10	6;9-12;3
RA controls		
Mean	9;3	9;6
sd	20.57	20.93
range	7;4-12;3	7;3-12;9
CA controls		
Mean	14;6	15;0
sd	9.64	20.84
range	13;9-16;0	12;9-17;0

All the participants were from York primary and secondary schools. All participants were administered the WORD Basic Reading Subtest, a test of single word reading. A reading age was calculated from the raw scores. Each dyslexic was matched with a reading age control within six months of their reading age, and a chronological age match within six months of their chronological age.

4.2.2.2 Design and Materials

A paired associate (PA) learning task was constructed involving four pictures of abstract paintings (3 in. x 5 in.), each to be paired with a nonword (see Appendix D). There were two one syllable nonwords (e.g. lazz, vob) and two three syllable nonwords (e.g. lasious, noliet). Participants were presented with one of two versions of the visual-verbal pairs in the learning trials. Half of the children were taught the first order of the visual-verbal pairs, and the remaining participants the second order of pairs. This was to ensure that differences in the salience of visual-verbal pairs would not bias results. The actual order of presentation in the test trials was randomised by shuffling the cards before each trial.

4.2.2.3 Procedure

Each participant was tested within their school. Participants were shown a card, and taught its matching nonword. Participants were asked to repeat the nonword and to carefully look at the card. This was done for each of the four cards. The whole procedure was repeated a second time. Test trials did not begin until participants were able to pronounce the nonwords, which always occurred within two test trials. The instructions were as follows:

> I'm going to show you four cards. They have funny paintings and shapes on them, and I have given them my own made up names. I'm going to show you each card and teach you my special name for each funny picture. I want you to repeat each name after me. Look carefully at the picture I'm showing you.

After the card-nonword pairs were shown to the participants twice, the instructions were as follows: "Now, I'm going to shuffle these cards, and I want to see if you can remember the name that goes with each picture. Ready?"

All four cards were presented in a random order over ten trials. Corrective feedback was given to each participant if the attempt was incorrect. If the participant correctly remembered the match, an acknowledgement of the correct match was made. Scores were derived from the number of times each item was correctly remembered, out of ten trials. In addition, an overall number of correctly remembered pairs was derived from a total of 40 possible correct responses. Responses over trials were also noted for later qualitative analysis.

4.2.3 Results

4.2.3.1 Paired Associate Learning

The performance of dyslexics, RA controls and CA controls on the paired associate learning task is shown in Table 4.2. Dyslexics performed like RA controls, and consistently worse than CA controls across all four nonwords. When trials for each nonword were combined into an overall score, dyslexics obtained a lower mean than RA controls and CA controls.

Table 4.2

Mean scores on paired associate learning for dyslexics and normal readers (RA controls; CA controls)

Group	Nonwords				Total Correct
	Vob (Max=10)	Lazz (Max=10)	Lasious (Max=10)	Noliet (Max=10)	(Max=40)
Dyslexic					
Mean	5.86	5.80	6.20	3.60	21.46
sd	2.74	2.78	2.48	2.94	5.91
RA controls					
Mean	6.26	6.66	7.6	5.33	26.26
sd	2.89	2.89	2.06	2.46	6.85
CA controls					
Mean	8.40	8.73	8.00	6.86	32.2
sd	1.68	1.62	1.85	1.76	4.27

A one way analysis of variance was conducted on the total learning scores with one between subjects factor, Group (dyslexics; RA controls; CA controls). This revealed a significant effect of group ($F(2,42) = 12.98$, $MSe=33.40$, $p<.001$). Post hoc analyses (Newman Keuls) revealed dyslexics performed significantly worse than both CA controls ($p<.001$) and RA controls ($p<.05$), who in turn performed significantly worse than CA controls ($p<.01$).

Next, the relative difficulty of learning the one and three syllable labels for the visual stimuli was assessed. The means and standard deviations are given in Table 4.3.

Table 4.3

Number of correct responses in the paired associate learning task as a function of length, for dyslexics and normal readers (RA controls; CA controls)

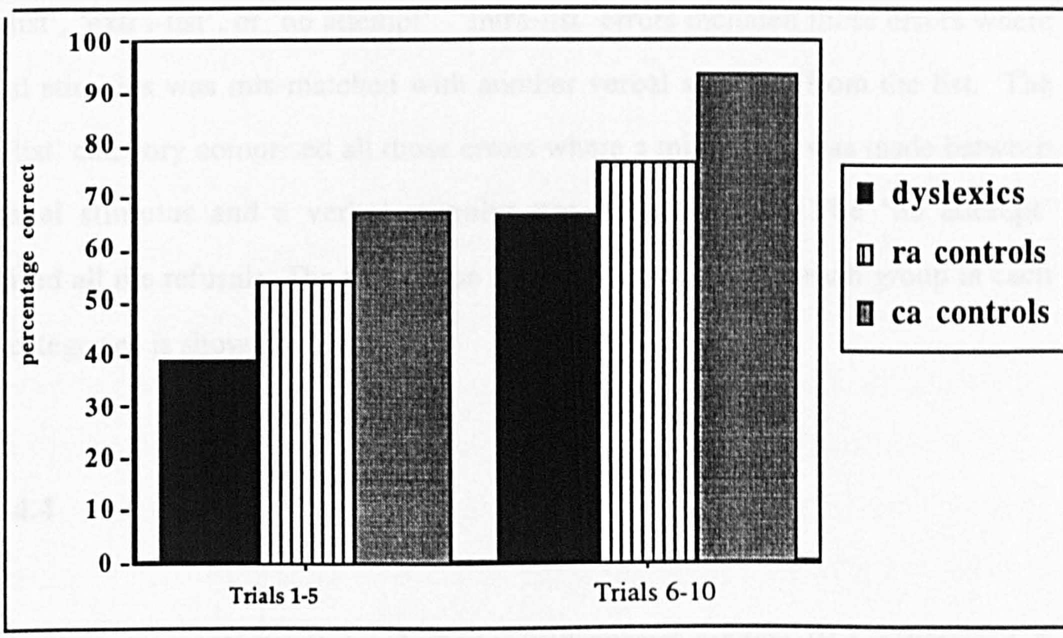
		Syllable Length	
Groups		One syllable	Three syllable
Dyslexic			
	Mean	5.83	4.9
	sd	1.99	2.12
RA controls			
	Mean	6.46	6.46
	sd	2.70	2.11
CA controls			
	Mean	8.56	7.43
	sd	1.22	1.38

An analysis of variance was conducted with one between subjects factor, Group (dyslexics; RA controls; CA controls) and one within subjects factor, Item Length (one syllable; three syllables). Analyses revealed a significant effect of group ($F(2,42)=12.91$, $MSe=52.48$, $p<.001$). There was no main effect of length. Post hoc analyses (Newman Keuls) revealed dyslexics performed significantly worse than CA controls ($p<.001$) and RA controls ($p<.05$), who performed significantly worse than CA controls ($p<.01$).

To assess the rate of learning in the two groups, the number of correct responses after 5 and 10 trials was calculated for dyslexics, RA controls and CA controls. The data is shown in Figure 4.1.

Figure 4.1

Graph showing the mean scores on paired associate learning, as a function of trial for dyslexics and normal readers (RA controls; CA controls) on trials 1-5, and trials 6-10



An analysis of variance was carried out on these data with one between subjects factor, Group (dyslexics; RA controls; CA controls) and one within subjects factor, Trial Time (1-5; 6-10). This analysis revealed significant main effects of group ($F(2,42) = 14.05$ $MSe=15.95$, $p<.001$), and trial time ($F(1,42) = 129.47$, $MSe=4.61$, $p<.001$). No interactions were found ($F(2,42)=.32$, $p>.05$).

Post hoc analyses (Newman Keuls) of group revealed dyslexics performed significantly worse than CA controls ($p<.001$) and RA controls ($p<.05$), who in turn performed significantly worse than CA controls ($p<.01$).

4.2.3.2 Paired Associate Learning Errors

The corpus of errors on the paired associate learning task was examined to determine the types of errors made by each group of participants. Error categories were established, following scrutiny of the transcriptions. Errors were classified as a 'intra-list', 'extra-list', or 'no attempt'. 'Intra-list' errors included those errors where a visual stimulus was mis-matched with another verbal stimulus from the list. The 'extra-list' category comprised all those errors where a mis-match was made between the visual stimulus and a verbal stimulus not from the list. The 'no attempt' comprised all the refusals. The proportion of errors committed by each group in each of the categories is shown in Table 4.4.

Table 4.4

Classification of errors made by dyslexics and normal readers (RA controls; CA controls) in the paired associate learning task

	Group		
Errors	Dyslexics (N=289)	RA controls (N=211)	CA controls (N=117)
Intra List Response	.20	.21	.22
Extra List Response	.64	.58	.62
No Response	.16	.21	.16

As shown in Table 4.4, dyslexics committed more errors than both RA and CA controls. However, all the groups committed approximately the same proportion of errors in each error category. This data is consistent with the quantitative data, showing that dyslexics are worse on the PA learning task overall.

4.3 Discussion

Thus, the results of the present study replicated the finding that poor readers are significantly worse than good readers in visual-verbal paired associate learning (Vellutino et al., 1979; Vellutino et al., 1995; Wimmer et al., 1997). Importantly, the present data showed that dyslexics were worse than younger RA controls. Furthermore, the analyses examining the learning curves of the three groups revealed that dyslexics performed significantly worse than both control groups. Most striking was the finding that dyslexics' peak performance in trials 6-10, was approximately the level of performance obtained in trials 1-5, for the chronological age controls. Importantly, all groups performed better on trials six through ten than on trials one through five. This suggests that group differences were not a result of different patterns of performance between the two halves of the task.

However, the error analyses showed the proportion of 'intra list', 'extra list' and 'no response' errors were similar for all three groups. This suggests that dyslexics showed a similar pattern of errors, although they committed quantitatively more errors than normal readers. Moreover, it appears that all subjects had the most difficulty in learning the response item in the paired associate learning task, as revealed by the higher proportion of extra-list responses.

Finally, the results are consistent with the hypothesis that tasks which are more directly related to reading show greater deficits than tasks which are indirectly associated with reading. When learning to read, children learn to associate the sound of a word, with its written form (e.g. /kæt/ - cat). Similarly, in a paired associate task, children are asked to associate a novel verbal response, with a visual stimulus.

Experiments 1 and 2 showed that poor readers performed comparably to younger reading age controls on verbal short-term memory task. The findings raise the question of the relationship between paired associate learning and reading skill. It seems clear that paired associate learning is a stronger predictor of reading than memory span. However, its relationship to other measures of phonological processing such as phonological awareness and speech rate remain to be determined.

Chapter Five

An Investigation into the Interrelationships between Verbal Learning Skills, Verbal Short Term Memory, and Phonological Awareness in Normal Reading Children

5.1 Overview

This chapter reports a large-scale study of 75 normal reading children aged seven to eleven. The aims of the study were to investigate the relationships among reading, phonological processing skills, and paired associate learning.

5.2 Study 4

5.2.1 Introduction

McDougall (1994) showed that the association between reading and phonological processing could plausibly explain the association between reading and verbal short-term memory. In other words, memory span may simply be one way of tapping underlying phonological processing skills. The results of Experiments 1 through 3 are in line with the view that tasks more analogous to reading (e.g. phonological awareness or paired associate learning) are more closely associated than tasks which share fewer of the same processing demands required in reading (e.g. verbal short term memory). Consistent with McDougall et al., (1994) we expected to find closer associations between phonological awareness tasks and reading, than verbal memory tasks and reading.

Furthermore, Wagner, Torgesen, & Rashotte (1994) proposed that phonological processing comprised multiple highly correlated latent abilities, identified as phonological analysis, phonological synthesis, phonological coding in working memory, isolated naming, and serial naming. In Experiment 3, paired associate learning appeared a sensitive measure of the ability to learn novel words. We wanted to investigate whether paired associate learning is encompassed by one of the latent variables proposed by Wagner et al., or whether it comprises a separate factor in the prediction of reading skill.

5.2.2 Method

5.2.2.1 Participants

The study involved 75 normal reading children. All the participants were from a York area primary school. Participants were administered the WORD Basic Reading Subtest (test of single word reading) to establish reading ages. Details of the participants are shown in Table 5.1.

Table 5.1

Participant details of seven, eight, nine, ten, and eleven year olds

Age Group N=15 /group	Chronological ages	Reading Ages
7 years		
Mean	7;4	7;3
sd	3.49	7.79
range	7;1-7;4	6;3-8;8
8 years		
Mean	8;3	8;3
sd	2.32	29.28
range	8;0-8;7	6;8-12;8
9 years		
Mean	9;4	10;3
sd	3.36	23.14
range	9;2-9;11	8;3-14;0
10 years		
Mean	10;1	9;8
sd	2.89	19.10
range	10;0-10;11	7;8-13;4
11 years		
Mean	11;4	11;6
sd	3.62	18.88
range	11;0-11;11	9;3-15;0

5.2.2.2 Design and Materials

A test of phoneme deletion comprised 24 nonwords (McDougall et al., 1994) (see Appendix E). Position of the sound to be deleted from each nonsense word was counterbalanced across trials. The sounds to be deleted were either single phonemes, or one phoneme of a consonant clusters (e.g. **b**ice; tea**p**; c**l**art, cro**t**s). One point was awarded for each correct answer.

The rhyme oddity task (Snowling, Hulme, Smith & Thomas, 1994) comprised 26 blocks of four one syllable words (see Appendix F). One word in each block of four words did not rhyme with the others (e.g. pad-had-**bat**-mad). The position of each non-rhyming word in a block of four was counterbalanced across trials. One point was awarded for each correct answer.

The paired associate learning task used in this experiment was constructed by pairing abstract shapes with spoken nonwords (see Appendix G). The shapes were rated for complexity and associability (Vanderplas & Garvin, 1959). They were selected from the group of 12-point shapes, which were classed as moderate in complexity. Moreover, the shapes were the lowest in associability, for this complexity group. The shapes were used to ensure that the visual stimuli were as neutral as possible, making the task more sensitive.

Four nonwords were constructed from real words of equivalent frequency using norms from the MRC Database. There were two one syllable (e.g. stosp, taith) and two three syllable items (e.g. meferal, balio). 'Stosp' and 'taith' were constructed from 'stock' and 'faith'. To increase the level of difficulty for one-syllable items, the final phoneme in stock was substituted with the consonant cluster 'sp' instead of a single phoneme. The vowel positions were maintained. The initial phoneme in faith was substituted with an alternate phoneme. 'Meferal' and 'balio' were constructed from 'federal' and 'radio'. To increase the difficulty of three syllable nonwords both initial and medial positions were changed to create the nonword. The vowel positions were maintained.

Fourteen one-syllable words and 14 one-syllable nonwords were used in the memory span task (see Appendix H). Words were selected from the Phonological Neighbour Program (Roodenrys, unpublished), whose word base was collected from the Oxford Psycholinguistic database (Quinlan, 1992). Phonological neighbourhoods were defined as those items, which deviated from the target, word by one phoneme. Half of the one-syllable words were high phonological neighbourhood words (e.g. post, cold), half were low phonological neighbourhood words (e.g. land, jazz). All words were matched for frequency.

One-syllable nonwords were constructed from each word through consonant substitution in initial or medial positions. Vowel positions were always maintained. Nonwords were grouped into high phonological neighbourhood nonwords (e.g. dost, jold) and low phonological neighbourhood nonwords (e.g. gand, vazz).

5.2.2.3 Procedure

Participants were tested in a quiet area within their school. All participants received two testing sessions. The first testing session lasted approximately 30 minutes. The WORD Test of Basic Reading was administered first, followed by the

WISC Vocabulary Subtest, WISC Block Design Subtest, and the Graded Nonword Reading Test.

Two phonological awareness tests were administered next. Prior to the administration of the rhyme oddity task, each child was given three practice trials, which tested their understanding of rhyme. Corrective feedback was given if practice trials were incorrect. Following, each child was instructed to listen to four words spoken aloud by the experimenter. Each child was asked to choose the 'odd one out'.

The test of phoneme deletion followed. Each child was asked to first listen to a nonsense word spoken aloud by the experimenter. Following this, the experimenter deleted a phoneme from the target item. The child was then asked to verbalise the remaining 'word'. Eight practice trials were given, and corrective feedback was provided if practice trials were incorrect.

The second testing session lasted approximately 20 minutes. It comprised the paired associate learning task, and a memory test of word and nonwords. In the paired associate task, each child was shown four abstract shapes and taught the nonsense name of each shape. Participants were asked to repeat the nonword while carefully looking at each abstract shape. The whole procedure was repeated a second time. Test trials did not begin until each child was able to pronounce each of the nonwords. The instructions were as follows:

> I'm going to show you four cards. Each card has one shape on it. I have given each one my own made-up name. What I'm going to do is show you each card and teach you my special name for each shape. I want you to repeat each name after me. Look carefully at the card I'm showing you.

After the abstract shape/nonword pairs were shown to the children twice, the instructions were as follows: "Now, I'm going to shuffle these cards, and I want to see if you can remember the name that goes with each shape. Ready?"

One point was awarded when the spoken items matched the correct visual stimuli. An overall number of correctly remembered pairs was derived from a total of 80 possible correct responses (20 trials x 4 items/block). In addition, a separate score was calculated for one- and three syllable response items correctly learned.

All four shapes were presented in a random order over twenty trials. Corrective feedback was given to the participant if the attempt was incorrect. If the participant correctly remembered the match, an acknowledgement of the correct match was made. Responses were recorded via DAT and also noted for later qualitative analysis.

The memory task was administered last. Each child was instructed to listen to the items in each list and repeat the list of items in the order the experimenter spoke them. Lists of words were presented first, followed by nonword lists. Each list was presented in blocks of two, with a beginning list length of two items. Each list was randomised by the experimenter. The lists were spoken aloud at one item per second. Each child was asked to repeat the list in the correct order. The test was discontinued when the child missed two consecutive trials in any given block. Scores were calculated by assigning one point for each correctly remembered list. The task was recorded via Digital Audio Tape (DAT) for later analysis.

5.2.3 Results

5.2.3.1 Descriptive Statistics

The means and standard deviations of all the measures for all 75 subjects are given in Table 5.2(a-b). The skewness of all the measures was examined to ensure that performance on all variables followed a normal distribution. Only nonword reading showed a slightly negative skew, which may be have resulted from ceiling effects. However, all measures ranged between -1.5 and 1.5.

Table 5.2a

Mean scores for verbal and nonverbal measures for seven to eleven years olds

	Measures			
Age Groups	WORD Reading	WISC Vocabulary	Block Design	Nonword Reading
7 years				
Mean	24.73	17.86	15.6	10.66
sd	5.13	4.12	9.43	5.14
8 years				
Mean	31.16	25.08	22.00	12.58
sd	8.41	4.23	11.35	4.95
9 years				
Mean	37.66	24.53	28.00	17.46
sd	5.84	6.37	9.21	3.83
10 years				
Mean	36.93	26.60	31.60	17.47
sd	5.11	7.22	9.51	3.14
11 years				
Mean	42.53	30.6	43.26	18.4
sd	3.11	4.18	10.49	1.76

Table 5.2 b

Mean scores for phonological processing tasks for seven to eleven years olds

Age Groups		Measures				
		Rhyme Oddity	Phoneme Deletion	PA Learning	Memory Words	Memory Nonword
7 years						
	Mean	14.53	10.2	25.46	4.73	2.13
	sd	4.32	3.09	11.92	1.03	.99
8 years						
	Mean	17.06	13.82	35.02	4.38	2.61
	sd	4.62	4.25	16.80	1.88	1.14
9 years						
	Mean	20.07	17.15	45.85	5.31	3.23
	sd	5.23	3.19	22.81	1.60	1.32
10 years						
	Mean	19.66	18.33	37.73	5.33	2.87
	sd	3.84	2.41	17.35	1.40	.91
11 years						
	Mean	21.66	18.06	51.53	5.93	3.26
	sd	2.69	3.97	12.98	1.16	.70

Partial correlations (controlling for chronological age) among the variables are shown in Table 5.3. As expected, there were high correlations between reading and nonword reading ($r=.63$, $p<.001$), rhyme oddity ($r=.59$, $p<.001$), and phoneme deletion ($r=.58$, $p<.001$). Moderate correlations were found between rhyme oddity and phoneme deletion ($r=.44$, $p<.001$), and between rhyme oddity and nonword reading ($r=.46$, $p<.001$) and phoneme deletion and nonword reading ($r=.64$, $p<.001$). The correlations between memory for words and memory for nonwords was moderate ($r=.44$, $p<.001$).

Table 5.3 a

Partial correlations (controlling for chronological age) between measures of reading, phonological processing and phonological memory

	1	2	3	4	5	6	7
(1) WORD Reading		.63***	.59***	.58***	.56***	.28*	.18
(2) Nonword Reading			.46***	.64***	.49***	.20	.16
(3) Rhyme Oddity				.44***	.47***	.22	.38 **
(4) Phoneme Deletion					.42***	.33**	.28*
(5) PA Learning						.15	.18
(6) Memory for Words							.44***
(7) Memory for Nonwords							

* p<. 05

** p< .01

*** p<.001

Importantly, there was also a strong correlation between reading and paired associate learning (r=.56, p<.001). Moderate correlations were also found between paired associate learning and rhyme oddity (r=.47, p<.001), and paired associate learning and phoneme deletion (r=.42, p<.001).

In contrast, low correlations were found between reading age and memory for words (r=.28, p<.05) and memory for nonwords (r=.18), nonword reading and memory for words (r=.20) and nonwords (r=.16). Moreover, low correlations were found among rhyme oddity and memory for words (r=.22), and memory for nonwords (r=.38), and phoneme deletion and memory for words (r=.33, p<.01) and memory for nonwords (r=.28, p<.05). Interestingly, low correlations were found between paired associate learning and memory for words (r=.15) and memory for nonwords (r=.18).

The relationship between reading and measures of phonological awareness, phonological learning and memory were investigated separately in each age group. Selected correlations for each age group are shown in Table 5.4.

Table 5.3b

Correlations between reading and measures of phonological awareness, phonological learning, and memory for 7, 8, 9, 10, and 11 year olds.

	Word Reading Ability				
	7 yrs	8 yrs	9 yrs	10 yrs	11 yrs
Phoneme Deletion	.32	.83*	.38	.53*	.54*
Rhyme Oddity	.51*	.62*	.73*	.26	-.26
PA Learning	-.09	.69*	.70*	.56*	.34
Memory for Words	.25	.45	.16	.17	.16
Memory for Nonwords	.19	.02	.13	.41	-.33

* p<.05

It is clear that all the groups showed strong correlations between paired associate learning and word reading, except for the 7 year old group and the 11 year old group. Reasonably, the 7 year old group performed at floor on the rhyme task, resulting in a weak correlation between WORD reading and rhyme oddity. Plausibly, the weak correlations between reading and PA learning in the 11 year old group resulted from outliers in the PA learning task.

The relationship between phoneme deletion and word reading was moderate to strong in all the groups, except for the 7 and 9 year olds. Reasonably, the weak correlation between reading and phoneme deletion in the 7 year old group was a result of floor effects in the phoneme deletion task. Closer examination of the 9 year olds performance showed that the weak correlation between phoneme deletion and reading may have resulted from outliers in the data. Moreover, all the groups showed moderate to strong correlations between WORD reading and rhyme oddity, except the 10 and 11 year olds. Arguably, rhyme oddity is a less sensitive measure of phonological awareness in older children than tests of fine grained phonological awareness, such as phoneme deletion. Furthermore, correlations between memory for word and nonword learning, and WORD reading showed weak correlations among all the age group.

5.2.3.2 The Interrelationship between Reading, Phonological Awareness, Verbal Memory, and Paired Associate Learning.

The relationship between reading, phonological awareness, memory, and paired associate learning was investigated further in a series of multiple regression analyses. The first set of analyses were concerned with assessing the concurrent predictors of reading ability. To reduce the number of variables entered into these regressions composite variables were formed for phonological awareness and memory, by taking the average of the z-scores for phoneme deletion and rhyme oddity, and memory for words and memory for nonwords. These composite variables together with paired associate learning were used as independent variables in a model predicting reading ability. Chronological age, and Block Design were always entered in at Step 1, and Vocabulary knowledge (WISC-II Vocabulary) was always entered in at Step 2 to control for individual differences in age and IQ. Paired associate learning, phonological awareness composite (phoneme deletion, rhyme oddity), and memory span composite (word span, nonword span) were entered in alternate orders at Steps 3, 4, and 5 to assess their importance in the prediction of reading ability. The results of these analyses are given in Table 5.4.

Table 5.4

Hierarchical multiple regression analyses predicting reading ability (I)

Step	Variable	β	R^2 Change	Significance
1	Chronological Age	.63	.48	.00
	Block Design	.08	-----	-----
2	WISC Vocabulary	.25	.04	.03
3	PA Learning	.42	.16	.00
4	Phonological Awareness	.44	.04	.00
5	Memory	-.02	.00	.82
3	Memory	.17	.17	.02
4	PA learning	.41	.14	.00
5	Phonological Awareness	.45	.08	.00
3	Phonological Awareness	.59	.21	.00
4	Memory	-.01	.00	.86
5	PA Learning	.23	.03	.01

The results of the regressions analyses showed that age and IQ. accounted for approximately 50% of the variance in reading skill. Furthermore, paired associate learning and phonological awareness measures accounted for independent proportions of the prediction of reading ability. In contrast, memory skills accounted for unique variance only in Step 3. The variance accounted for by memory span was subsumed by phonological awareness when entered in Steps 4 and 5.

Further analyses were carried out to investigate the independent contributions of phoneme deletion and rhyme oddity to reading ability. Memory span was omitted, as it did not contribute any unique variance in the final steps of this regression analysis. Chronological age, and Block Design were entered in at Step 1, and Vocabulary knowledge (WISC-III Vocabulary) at Step 2, to control for individual differences in age and IQ. Paired associate learning, phoneme deletion, and rhyme oddity were entered in alternate orders at Steps 3, 4 and 5. The results are shown in Table 5.5.

Table 5.5

Hierarchical multiple regressions analyses predicting reading ability (II)

Step	Variable	β	R^2 Change	Significance
1	Chronological Age	.63	.48	.00
	Block Design	.08	-----	-----
2	WISC Vocabulary	.25	.04	.02
3	PA Learning	.42	.16	.00
4	Phoneme Deletion	.33	.06	.00
5	Rhyme Oddity	.24	.03	.01
3	Rhyme Oddity	.46	.15	.00
4	PA Learning	.29	.06	.00
5	Phoneme Deletion	.25	.03	.00
3	Phoneme Deletion	.48	.15	.00
4	Rhyme Oddity	.32	.06	.00
5	PA Learning	.23	.03	.00

The results of the analyses show that both phoneme deletion and rhyme oddity accounted for independent variance in the prediction of reading ability. Although phoneme deletion subsumed some of the variance contributed by rhyme oddity, rhyme oddity still made a significant contribution in the last step. Again, paired associate learning accounted for unique variance in reading ability.

A second set of regression analyses were conducted to investigate the contribution of paired associate learning, phonological awareness, and memory to the prediction of nonword reading ability. Chronological age and Block Design were always entered in at Step 1, and Vocabulary knowledge (WISC-III Vocabulary) was always entered in at Step 2 to control for individual differences in age and IQ. Paired associate learning, phonological awareness (phoneme deletion, rhyme oddity) and memory (memory for words, memory for nonwords) were entered in alternate orders at Steps 3, 4, and 5. The results of these analyses are given in Table 5.6.

Table 5.6

Hierarchical multiple regressions analyses predicting nonword reading (I)

Step	Variable	β	R^2 Change	Significance
1	Chronological Age	.51	.31	.00
	Block Design	.06		
2	WISC Vocabulary	.02	.00	.86
3	PA Learning	.44	.16	.00
4	Phonological Awareness	.60	.16	.00
5	Memory	-.04	.00	.63
3	Memory	.19	.03	.08
4	PA Learning	.41	.14	.00
5	Phonological Awareness	.61	.15	.00
3	Phonological Awareness	.70	.31	.00
4	Memory	-.04	.00	.64
5	PA Learning	.18	.02	.05

The results of these analyses showed that age and IQ. accounted for approximately 30% of the variance in the prediction of nonword reading ability. Furthermore, paired associate learning and phonological awareness accounted for unique variance in the prediction of nonword reading ability. Phonological awareness was the strongest predictor in the final step. Phonological awareness accounted for 15% of the variance in the final step, compared to paired associate learning which contributed only 2% in the final step. Memory did not contribute significant variance to nonword reading at any step.

A second set of analyses was conducted to assess the individual role of phoneme deletion and rhyme oddity , and paired associate learning as predictors of nonword reading. Chronological age and Block Design were entered in at Step 1, and Vocabulary knowledge (WISC-III Vocabulary) was entered in at Step 2. Paired associate learning, phoneme deletion, and rhyme oddity were entered in alternate orders at Steps 3, 4, and 5. The results of the analyses are given in Table 5.7.

Table 5.7

Hierarchical multiple regression analyses predicting nonword reading (II)

Step	Variable	β	R^2 Change	Significance
1	Chronological Age	.51	.31	.00
	Block Design	.06		
2	WISC Vocabulary	.02	.00	.86
3	PA Learning	.44	.16	.00
4	Phoneme Deletion	.57	.17	.00
5	Rhyme Oddity	.15	.01	.13
3	Rhyme Oddity	.45	.15	.00
4	PA Learning	.31	.07	.00
5	Phoneme Deletion	.53	.13	.00
3	Phoneme Deletion	.68	.30	.00
4	Rhyme Oddity	.21	.03	.02
5	PA Learning	.18	.02	.04

The results of the regression analyses showed that only paired associate learning and phoneme deletion accounted for independent variance in Step 5. However, phoneme deletion was a stronger predictor than paired associate learning, as it contributed 13% of the variance in the final step, compared to paired associate learning which contributed only 2% of the variance in the final step. Moreover, phoneme deletion was a stronger predictor of nonword reading ability than rhyme oddity. Phoneme deletion subsumed some of the variance contributed by rhyme oddity.

A third set of analyses were conducted to assess the role of different cognitive skills as predictors of paired associate learning. Chronological age and Block Design were entered in at Step 1, and Vocabulary knowledge (WISC-III Vocabulary) was always entered in at Step 2 to control for age and IQ. Phonological awareness (phoneme deletion, rhyme oddity), and memory (word memory, nonword memory) were entered in alternate orders at Steps 3 and 4. The results of the analyses are given in Table 5.8.

Table 5.8

Hierarchical multiple regression analyses predicting paired associate learning (I)

Step	Variable	β	R^2 Change	Significance
1	Age	.38	.14	.01
	Block Design	-.02		
2	WISC Vocabulary	.06	.00	.67
3	Phonological Awareness	.60	.22	.00
4	Memory	.01	.00	.95
3	Memory	.20	.03	.10
4	Phonological Awareness	.60	.20	.00

The results showed that age and IQ accounted for approximately 14% of the variance in paired associate learning. Furthermore, phonological awareness accounted for unique variance at Steps 3 and 4, after Chronological age, Block Design, and Vocabulary knowledge were accounted for. In contrast, memory failed to account for a significant amount of variance at any step.

Further analyses were conducted to assess the independent contribution of phoneme deletion and rhyme oddity to paired associate learning. Memory was omitted, because it did not contribute any variance to paired associate learning in the initial analysis. Chronological age and Block Design were entered in at Step 1, and Vocabulary knowledge at Step 2 to control for individual differences in age and IQ. Phoneme deletion and rhyme oddity were entered in alternate orders at Steps 3 and 4.

The results of the analyses showed that rhyme oddity and phoneme deletion contributed independent variance to paired associate learning ability.

Table 5.9

Hierarchical multiple regression analyses predicting paired associate learning (II)

Step	Variable	β	R^2 Change	Significance
1	Age	.38	.14	.01
	Block Design	-.02		
2	WISC Vocabulary	.06	.00	.67
3	Phoneme Deletion	.49	.15	.00
4	Rhyme Oddity	.36	.08	.01
3	Rhyme Oddity	.49	.18	.00
4	Phoneme Deletion	.32	.05	.02

5.2.4 Discussion

First, we were interested in the relationship between paired associate learning, phonological processing tasks, and reading in normal readers. In line with McDougall et al., (1994), the results showed that phonological awareness was a good predictor of reading skill. Furthermore, memory span did not predict reading skill when entered in after phonological awareness. Plausibly, phonological awareness subsumes most of the variance contributed by memory span. This is in line with

McDougall et al. (1994) who showed that memory span was a poor predictor of reading skill.

Importantly, the results showed that paired associate learning contributed significant variance to reading skill, separate from phonological awareness. The independence of phonological awareness and paired associate learning skill is also supported by the results of the regressions analysis on nonword reading. The results of this analysis demonstrated that phonological awareness (phoneme deletion, rhyme oddity) accounted for greater amounts of variance in nonword reading skill than paired associate learning in the final step. This supports the view that skills that require similar processing demands, are more closely associated than tasks which are broadly associated. In other words, nonword reading and phonological awareness tasks both require the explicit manipulation of phonemes. In contrast, paired associate learning requires learning a novel visual stimuli, and linking it with a novel phonological form.

Speculatively, it is proposed that paired associate learning and phonological awareness tasks tap separate mechanisms in the reading process. Plausibly, phonological awareness tasks tap the phonological representations at the level required to set up mappings between phonemes and graphemes in an alphabetic system. Phonological awareness skills require explicit manipulation of the constituent phonemes of words. Thus, the ability to complete such a task is heavily constrained by the specificity of the underlying representations.

Paired associate learning may also tap the phonological representations at the level required to set up mappings between phonemes and graphemes. However, it does not *necessarily* require this sophisticated level of phonological awareness. Plausibly, a child could learn to associate the visual stimulus with larger segments of the word, such as the syllable, or, indeed the whole word.

However, it is important to stress that phonological awareness and paired associate learning were significantly correlated. Indeed, phonological awareness made a significant contribution to paired associate learning skill. Reasonably, paired associate learning and phonological awareness share the same underlying resource, phonological representations, as well as making unique contributions.

Finally, we were interested in examining the relationship between paired associate learning and phonological processing. Wagner et al., (1994) suggest that phonological memory (e.g. phonological coding in working memory) and phonological awareness are two latent abilities comprising phonological processing. Indeed, the results of Experiment 4 showed that paired associate learning was moderately associated with phonological awareness tasks, although non-significantly correlated with verbal memory span. Thus, the results are equivocal about the status of paired associate learning as a separate, yet highly correlated latent variable. The results presented here suggest that examining paired associate learning in this context warrants further investigation.

Chapter Six

An Experimental Investigation of the Interrelationships Between Verbal Short Term Memory, Phonological Awareness and Paired Associate Learning in Normal Reading and Dyslexic Children

6.1 Overview

This chapter reports two experiments investigating the relationship among verbal short term memory, speech rate, phonological awareness and paired associate learning in dyslexics, RA controls and CA controls. The first experiment is a cross-sectional study of dyslexic readers, RA controls and CA controls. The main aim of this experiment was to investigate the differences between dyslexics and normal readers in verbal learning skills, verbal short term memory, phonological awareness and paired associate learning. Furthermore, performance on the paired associate learning task was examined to determine if there was a qualitatively different pattern in the strategies used by the dyslexic and normal readers ability to learn visual-verbal associations.

The second experiment was a small scale study investigating the relationship among paired associate learning, phonological awareness and speech rate in normal and dyslexic readers. A secondary aim of this experiment was to clarify the speech rate results of experiment 1 and 2.

6.2 Experiment 5

6.2.1 Introduction

There were three main aims of Experiment 5. First, we wanted to replicate the finding of a deficit in paired associate learning in dyslexic readers, compared to RA controls and CA controls using more abstract visual stimuli. Second, we were interested in the relationships among phonological awareness tasks, PA learning, verbal short term memory and reading in dyslexic readers. The results of Experiment 4 showed that paired associate learning contributed unique variance to reading skill in normal readers. Consistent with Experiment 4, we expected to see a strong relationship between PA learning, phonological awareness and reading for the normal readers, and a weaker association between verbal short term memory tasks and the other variables (McDougall, et al., 1994). Conversely, we expected that dyslexics would show difficulties with phonological awareness tasks. We anticipated that dyslexics would have difficulty learning the response items in the paired associate learning task because they are worse at creating phonological representations. Finally, we anticipated that they would have difficulty learning the link between the visual and the verbal stimuli.

6.2.2 Method

6.2.2.1 Participants

The study involved 15 dyslexic readers, 15 reading age controls, and 15 chronological age controls. The details of the participants is shown in Table 6.1. All the participants were from York area schools. Each child was administered the WORD Basic Reading Subtests (test of single word reading) to establish reading ages. Each dyslexic reader was matched with a reading age control within six months of their reading age, and a chronological age match within six months of their chronological age.

Furthermore, all the children comprising the dyslexic sample were diagnosed as dyslexic, and statemented as such. Ten of the dyslexics in the present sample had also participated in Experiment 3. Nine of the dyslexics in the present experiment had also participated in Experiment 2, while none of the participants in the present study participated in Experiment 1 (see Appendix K4 for details of dyslexics). Overall, ten of the participants in Experiment 5, had also participated in Experiments 2 and 3.

Table 6.1

Participant details of dyslexics and normal readers (RA controls, CA controls)

Group	Age Ranges	
	Chronological age	Reading age
Dyslexics		
Mean	14;6	8;7
sd	10.12	24.80
range	13;1-15;9	6;3-12;9
RA controls		
Mean	8;6	8;7
sd	20.68	21.33
range	6;5-13;1	6;6-12;9
CA controls		
Mean	14;5	14;7
sd	9.91	23.20
range	13;1-15;8	11;3-17;00

6.2.2.2 Design and Materials

A test of phoneme deletion comprised 24 nonwords (McDougall et al., 1994) (see Appendix E). The position of the deleted sound was counterbalanced across trials. The deleted sounds were either single phonemes, or one phoneme of a consonant clusters (e.g. **b**ice; tea**p**; c**l**art, c**r**ots). One point was awarded for each correct answer.

The rhyme oddity task (Snowling et al., 1994) comprised 26 trials of four one syllable words (see Appendix F). One word in each block of four words did not rhyme with the others (e.g. pad-had-**bat**-mad). The position of each non-rhyming word in a block of four was counterbalanced across trials. One point was awarded for each correct answer.

The paired associate learning task used in this experiment was constructed by pairing abstract shapes with spoken nonwords (see Appendix G). The four shapes used in the paired associate learning task were rated for complexity and associability (Vanderplas & Garvin, 1959). These shapes were selected from the group of 12-point shapes, which were classed as moderately complex. The shapes were the four lowest in associability, for this complexity group.

Four nonwords were constructed from real words of equivalent frequency using norms from the MRC Database. There were two one syllable (e.g. stosp, taith) and two three syllable items (e.g. meferal, balio). 'Stosp' and 'taith' were constructed from 'stock' and 'faith'. To increase the level of difficulty for one syllable items, the final phoneme in stock was substituted with the consonant cluster 'sp' instead of a single phoneme. The vowel positions were maintained. The initial phoneme in faith was substituted with an alternate phoneme. 'Meferal' and 'balio' were constructed from 'federal' and 'radio'. To increase the difficulty of three syllable nonwords both initial and medial positions were changed to create the nonword. The vowel positions were maintained.

Fourteen one syllable words and fourteen one syllable nonwords were used in the memory span task (see Appendix H). Words were selected from the Phonological Neighbour Program (Roodenrys, unpublished), whose word base was collected from the Oxford Psycholinguistic database (Quinlan, 1992). Phonological neighbourhoods were defined as those items which deviated from the target word by one phoneme. Half of the one syllable words had high phonological neighbourhoods (e.g. post, cold), half had low phonological neighbourhoods (e.g. land, jazz). All the words were matched for frequency.

One syllable nonwords were constructed from each word through consonant substitution in initial or medial positions. Vowel positions were always maintained. Nonwords were grouped into high phonological neighbourhood nonwords (e.g. dost, jold) and low phonological neighbourhood nonwords (e.g. gand, vazz).

6.2.2.3 Procedure

Participants were tested in a quiet area within their school. All participants received two testing sessions. The first testing session lasted approximately 30 minutes. The WORD Test of Basic Reading was administered first, followed by the WISC Vocabulary Subtest, WISC Block Design Subtest, and the Snowling Graded Nonword Reading Test.

Two phonological awareness tests were then administered. Each child was given three practice trials, which tested their understanding of rhyme. Corrective feedback was given if practice trials were incorrect. Following, each child was instructed to listen to four words spoken aloud by the experimenter. Each child was asked to choose the 'odd one out'.

A test of phonological deletion was then administered. Eight practice trials were given. Corrective feedback was provided if practice trials were incorrect. Each child was asked to first listen to a nonsense word spoken aloud by the experimenter. Following this, the experimenter deleted one phoneme from the target item, and asked the child to verbalise the remaining item.

The second testing session lasted approximately 20 minutes. It comprised the paired associate learning task, and a memory test of word and nonwords. In the paired associate task, each child was shown four abstract shapes and taught the nonsense name of each shape. Participants were asked to repeat the nonword while carefully looking at each abstract shape. The whole procedure was repeated a second time. Test trials did not begin until each child was able to pronounce the nonword. The instructions were as follows:

> I'm going to show you four cards. Each card has one shape on it. I have given each one my own made-up name. What I'm going to do is show you each card and teach you my special name for each shape. I want you to repeat each name after me. Look carefully at the card I'm showing you.

After the abstract shape/nonword pairs were shown to the children twice, the instructions were as follows: "Now, I'm going to shuffle these cards, and I want to see if you can remember the name that goes with each shape. Ready?"

One point was awarded when the spoken items matched the correct visual stimuli. An overall number of correctly remembered pairs was derived from a total of 80 possible correct responses (20 trials x 4 items/block). In addition, a separate score was calculated for the correctly matched one- and three syllable items.

All four shapes were presented in a random order over twenty trials. Corrective feedback was given to each participant if the attempt was incorrect. If the participant correctly remembered the match, an acknowledgement of the correct match was made. Responses were recorded via DAT for later qualitative analysis.

The memory task was administered last. Each child was instructed to listen to the items in each list and repeat the list of items in the order the experimenter spoke them. Lists of words were presented first, followed by nonword lists.

Each list was presented in blocks of two, with a beginning list length of two items. Each list was randomised by the experimenter. The lists were spoken aloud at one item per second. Each child was asked to repeat the list in the correct order. The test was discontinued when the child missed two consecutive trials in any given block. Scores were calculated by assigning one point for each correctly remembered list. The task was recorded via Digital Audio Tape (DAT) for later analysis.

6.2.3 Results

The mean scores of the dyslexics, RA controls, and CA controls on the verbal and nonverbal tasks are given in Table 6.2.

Table 6.2

Mean scores on verbal and nonverbal measures for dyslexics and normal readers (RA controls, CA controls)

	Tasks			
Group	WORD Raw (Max=55)	WISC Vocabulary (Max=60)	WISC Block Design (Max=69)	Nonword Reading (Max=20)
Dyslexics				
Mean	30.73	30.93	43.46	10.20
sd	10.71	6.45	11.12	5.18
RA controls				
Mean	32.33	24.00	25.60	13.60
sd	9.44	8.83	14.18	5.15
CA controls				
Mean	47.86	36.53	46.60	18.26
sd	2.74	7.79	10.70	1.43

A one-way analysis of variance carried out on the Block Design data with one between subjects factor, Group (dyslexics; RA controls; CA controls) revealed a significant main effect of group ($F(2,24)=13.14$, $MSe=146.14$, $p<.001$). Post hoc analyses (Newman Keuls) showed that dyslexics were significantly better than RA controls ($p<.05$), but did not differ from CA controls, who in turn were significantly better than RA controls ($p<.001$). Thus, dyslexics were comparable to their peers in nonverbal ability.

A one-way analysis of variance was carried out on the WISC Vocabulary data, with one between subjects factor, Group (dyslexics; RA controls; CA controls). This analysis revealed a main effect of group (F(2,42)=9.83, MSe=16.92, p<.01). Post hoc analyses (Newman Keuls) showed that dyslexics were significantly better than RA controls (p<.05), who in turn were significantly worse than CA controls (p<.01). There were no significant differences between dyslexics and CA controls.

A one-way analysis of variance was carried out on the nonword reading data, with one between subjects factor, Group (dyslexics; RA controls; CA controls) revealed a main effect of group (F(2,42)=13.29, MSe=18.49, p<.001). Post-hoc analyses (Newman Keuls) showed dyslexics were significantly worse than CA controls (p< .001) and RA controls (p<.05), who in turn were significantly worse than CA controls (p<.001). Thus, dyslexics performed worse than RA and CA controls in nonword reading.

Table 6.3

Mean scores on phonological processing measures for dyslexics and normal readers (RA controls; CA controls)

Group	Rhyme Oddity (Max=24)	Phoneme Deletion (Max=26)	PA Learning (Max=80)	Memory for Words (Max=8)	Memory for Nonwords (Max=8)
	Tasks				
Dyslexics					
Mean	14.93	9.26	31.61	5.33	2.8
sd	4.21	5.04	14.05	1.58	.67
RA controls					
Mean	18.00	14.80	35.33	4.86	2.86
sd	4.39	4.82	17.81	1.35	1.18
CA controls					
Mean	23.60	19.80	56.93	6.40	4.00
sd	2.13	2.30	13.55	1.29	1.25

A one-way analysis of variance conducted on the rhyme oddity data, with one between subjects factor, Group (dyslexics; RA controls; CA controls) revealed a main effect of group ($F(2,42)=20.88$, $MSe=13.86$, $p<.001$). Post hoc analyses (Newman Keuls) of the rhyme oddity data revealed that dyslexics were significantly worse than CA controls ($p<.001$) and RA controls ($p<.05$), who in turn were significantly worse than CA controls ($p<.001$).

A one-way analysis of variance conducted on the phoneme deletion data, with one between subjects factor, Group (dyslexics; RA controls; CA controls) revealed a main effect of group (F(2,42)= 23.08, MSe=18.04, p<.001). Post hoc analyses (Newman Keuls) of the phoneme deletion data revealed that dyslexics were significantly worse than CA controls (p<.001) and RA controls (p<.01), who in turn were significantly worse than CA controls (p<.01). Thus, the dyslexic readers performed worse than CA and RA controls on tests of phonological awareness.

A one-way analysis of variance was conducted on the memory span data for words with between subjects factor, Group (dyslexics; RA controls; CA controls). This analysis revealed a main effect of group (F(2,42)=4.59, MSe=2.14, p<.05). Post hoc analyses (Newman Keuls) revealed that dyslexics had a shorter memory span than CA controls (p<.05), who in turn had a longer memory span than RA controls (p<.05). Dyslexics and RA controls did not differ in their memory span performance for words (p>.05).

A one-way analysis of variance was conducted on the memory span data for nonwords with between subjects factor, Group (dyslexics; RA controls; CA controls). This analysis revealed a main effect of group (F(2,42)=5.95, MSe=1.15, p<.01). Post hoc analyses (Newman Keuls) revealed that dyslexics had shorter memory spans than CA controls (p<.05), who in turn had longer memory span than RA controls (p<.01). Dyslexics and RA controls did not differ in their memory span performance for nonwords (p>.05).

Finally, a one-way analysis of variance was conducted on the paired associate leaning data collapsed across length, with between subjects factor, Group (dyslexics; RA controls; CA controls). This analysis revealed a main effect of group (F(2,42,) = 12.05, MSe=232.85, p<.001). Post-hoc analyses (Newman Keuls) revealed that dyslexics performed significantly worse than CA controls ($p<.001$), and comparable to RA controls, who in turn were significantly worse than CA controls ($p<.001$).

6.2.4 Paired Associate Learning Errors

The corpus of errors made during the paired associate learning task was examined to determine the types of association error made by each group of participants. Error categories were established, following scrutiny of the transcriptions. Errors were classified as 'intra list', 'extra-list' and 'no attempt' errors. There were three main error types in the paired associate learning task. First, the 'intra' list error occurred when the child incorrectly named the shape, using another novel word from the list. This type of error suggests that the participants were able to remember the response item, but experienced difficulty linking the response and the stimulus items. An 'extra-list' error occurred when the child incorrectly named the stimulus item, with a response item not from the list. This suggests that the participants experienced difficulty remembering the response- stimuli, although this type of error does not preclude the possibility that participants had difficulties 'linking' the two stimuli. Finally, participants committed 'no attempt' errors, which were refusals to attempt the task. The proportion of errors committed by dyslexics, RA controls and CA controls is shown in Table 6.4.

Table 6.4

Proportion of errors in the paired associate learning task for dyslexics and normal readers (RA controls; CA controls)

	Group		
Errors	Dyslexics N=710	RA controls N=601	CA controls N=348
Intra-list errors	.06	.25	.15
Extra-list errors	.81	.65	.59
No attempt	.12	.17	.18

An analysis of variance was carried out on the total number of errors with between subjects factor, Group (dyslexics; RA controls; CA controls). A significant main effect of Group ($F(2,42)=11.77$, $MSe=262.39$, $p<.001$) was found. Post hoc analyses (Newman Keuls) showed that dyslexics were comparable to RA controls ($p>.05$) but committed significantly more errors than CA controls ($p<.001$). In turn, CA controls committed significantly fewer errors than RA controls ($p<.001$).

As can be seen from the data shown in Table 6.4, dyslexics made a larger proportion of extra-list errors than both RA and CA controls. In contrast, dyslexics made a smaller proportion of intra-list errors than both RA and CA controls. This suggests that dyslexics had difficulty retaining the response item, and not necessarily the 'link' between the response and stimulus items. However, it appears that the task was generally difficult for all three groups. Indeed, it appears that all three groups committed the greatest proportion of errors in the 'extra-list' category.

6.2.5 The Relationship between Paired Associate Learning and Phonological Awareness

To investigate the relationship between phonological awareness and paired associate learning, the pattern of correlations among the variables for all three groups was examined. The data are shown in Table 6.5

Table 6.5

Correlations between PA Learning and phonological awareness tasks for dyslexics, and normal readers (RA controls; CA controls)

	Tasks	
Groups	Phoneme Deletion	Rhyme Oddity
Dyslexics	.09	.08
	(.75)	(.77)
RA controls	.66	.63
	(.01)	(.01)
CA controls	.58	.58
	(.05)	(.05)

The data revealed strong correlations between paired associate learning and rhyme oddity ($r=.66$, $p<.01$), and paired associate learning and phoneme deletion ($r=.63$, $p<.01$) for RA controls. Similarly, paired associate learning correlated significantly with rhyme oddity and phoneme deletion, ($r=.58$, $p<.05$), and ($r=.58$, $p<.02$) for CA controls. This is consistent with the regression analyses in Experiment 4, where phoneme deletion and rhyme oddity were shown to be good predictors of paired associate learning in normal readers. However, paired associate learning was not significantly correlated with rhyme oddity (r=.09, p=.75) or phoneme deletion (r=.08, p=.77) for dyslexics.

The relationship between phoneme deletion and paired associate learning for dyslexics, RA and CA controls is depicted in Figure 6.1(a-c). The relationship between rhyme oddity and paired associate learning is shown in Figure 6.2 (a-c). The data suggest that there was a dissociation between paired associate learning and phonological awareness in the dyslexic group. Indeed, there was greater variation in paired associate learning, than in the phoneme deletion or rhyme oddity tasks. Thus, the performance of dyslexics in PA learning ranged from moderate to poor, compared to consistently poor performance on phoneme deletion and rhyme oddity tasks. In contrast, the level of performance in PA learning was significantly associated with phonological awareness in good readers.

Figure 6.1 Graphs showing the relationship between paired associate learning and phoneme deletion for dyslexics (a.), RA controls (b.), and CA controls (c.), respectively.

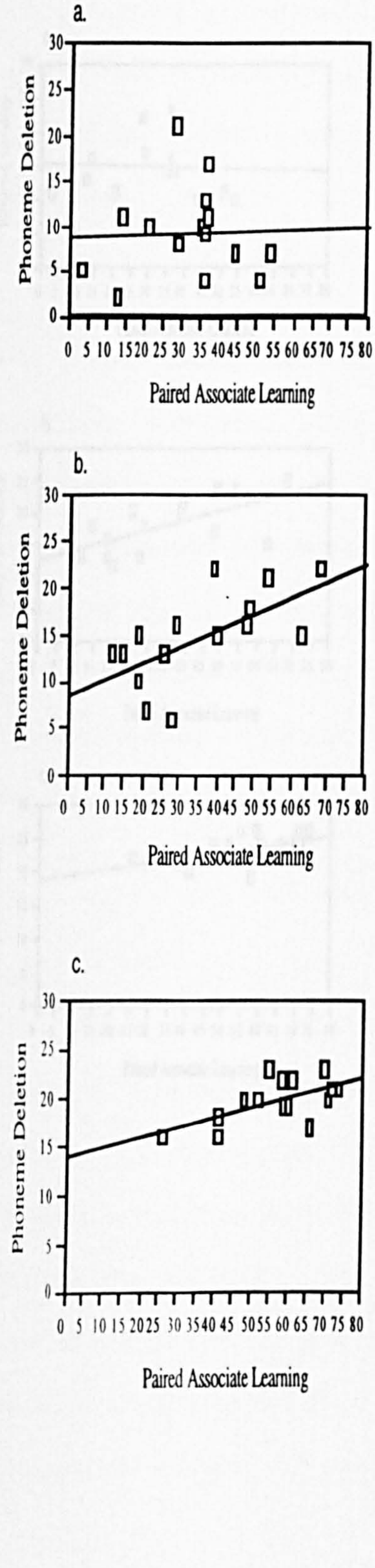
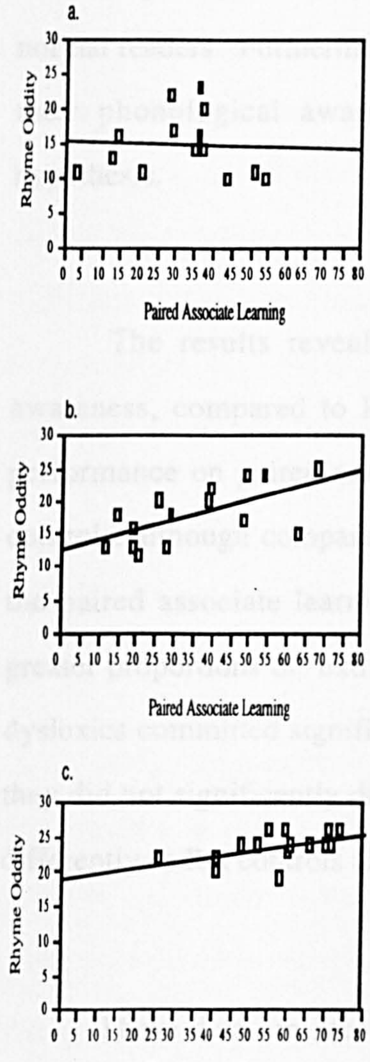


Figure 6.2 Graphs showing the relationship between rhyme oddity and paired associate learning for dyslexics (a.), RA controls (b.), and CA controls (c.), respectively.



6.2.6 Discussion

We predicted that dyslexics would show an impairment in their ability to link novel response and stimulus items in a paired associate learning task, compared to normal readers. Furthermore, we predicted that dyslexics would show impairments in their phonological awareness abilities, in line with the phonological deficit hypothesis.

The results revealed that dyslexics had an impairment in phonological awareness, compared to RA as well as CA controls. In addition, the dyslexics performance on paired associate learning was significantly worse than that of CA controls, although comparable to that of younger RA controls. An error analysis of the paired associate learning task revealed that dyslexics committed significantly greater proportions of 'extra-list' errors than both RA and CA controls. Conversely, dyslexics committed significantly fewer 'intra-list' errors than RA controls, although they did not significantly differ from CA controls. Importantly, dyslexics performed differently to RA controls although they were performing at a similar level to them.

These data are inconsistent with the hypothesis that dyslexics have greater difficulties 'linking' the response and stimulus items than normal readers do. Rather, the error analyses suggest that dyslexics experienced more difficulty learning the response items than both the RA and the CA controls. However, this does not preclude the possibility that they also had difficulty 'linking' the response and stimulus items. Indeed, all the groups experienced the greatest difficulty with 'extra-list' errors. Plausibly, the task was too difficult to be a sensitive measure of phonological learning difficulties. The results of Experiment 3 support this view, as significant differences were found between dyslexics and RA controls when the response and stimulus items were easier.

Closer examination of the correlations among paired associate learning, phoneme deletion, and rhyme oddity in the three groups showed a different pattern of correlations. While paired associate learning was strongly correlated with phonological awareness measures in both RA and CA controls, there was a dissociation between paired associate learning and phonological awareness for dyslexics. Plausibly, phonological awareness is more directly dependent on the access to well-specified phonological representations, whereas paired associate learning requires less fine grained phonological representations.

6.3 Experiment 6

In Experiments 1 and 2 (Chapter 3), we predicted that dyslexics would show impairments in speech rate comparable to their control groups (RA controls; CA controls). Contrary to our prediction, there were no group differences found in the quantitative analysis of the speech rate. However, error analyses in Experiments 1 and 2 revealed that the dyslexic group made greater numbers of errors compared to control groups. Thus, one aim was to investigate the relationship between paired associate learning and speech rate. The results of Study 4 (see Chapter 5) showed that memory span was not significantly associated with, and did not account for any variance in paired associate learning. Thus, it was predicted that speech rate would be weakly correlated with paired associate learning in normal and dyslexic readers, as memory span and speech rate are closely associated.

A second aim of Experiment 6 was to introduce a practice session for each participant, prior to the speech rate task. It was predicted that this would prevent errors, and thus provide a more accurate estimation of the true speech rate performance of dyslexics and RA controls.

Furthermore, we wanted to investigate the relationship between phoneme deletion and paired associate learning. In Experiment 5, there was a dissociation between phonological awareness measures and paired associate learning in the dyslexic group. In contrast, normal readers (RA controls; CA controls) showed a moderate association between paired associate learning and phonological awareness measures. Thus, a third aim of the present experiment was to replicate this finding.

A final aim of the present experiment was to further investigate the performance of RA controls and dyslexics on a paired associate learning task. In Experiment 3, dyslexics were significantly worse than younger RA controls on a paired associate learning task. In contrast, dyslexics performed *comparably* to RA controls in Experiment 5. Plausibly, the diverging results may have been a consequence of the different stimuli used in Experiments 3 and 5. Thus, the PA learning task in Experiment 6 was administered to reconcile the conflicting results.

6.3.1 Method

6.3.1.1 Participants

The study involved 15 dyslexic readers and 13 reading age matched participants. Details of the participants is shown in Table 6.6. All participants were from York area schools. Participants were administered the WORD Basic Reading Subtest (test of single word reading) to establish reading ages. Dyslexic readers were matched within 6 months of their reading age controls.

Furthermore, all the children comprising the dyslexic group were diagnosed as dyslexic, and statemented as such. Twelve of the dyslexics in the present experiments had also participated in Experiment 5, while six of the dyslexic children in the present study had also participated in Experiments 2 and 3. None of the children in Experiment 6 had participated in Experiment 1 (see Appendix K5 for details of dyslexics). Overall, seven dyslexic children had participated in Experiments 2,3,5, and 6.

Table 6.6

Participant details of dyslexics and normal readers (RA controls)

Group		Age Ranges	
		Chronological age	Reading age
Dyslexics			
	Mean	14;8	8;6
	sd	10.49	19.46
	range	13;2-15;11	6;6-12;3
RA controls			
	Mean	8;2	8;4
	sd	16.26	18.86
	range	6;6-10;3	6;6-11;9

6.3.1.2 Design and Materials

The phoneme deletion task (McDougall et al., 1994) was administered as a measure of phonological awareness (see Appendix E). The position of the deleted sound was counterbalanced across trials. The sound the child was required to delete, occurred either as a single phoneme or as part of a consonant cluster (e.g. bice; teap; clart; crots).

The speech rate task comprised three lists of nonsense words (see Appendix I). One list comprised 4 pairs of one syllable nonsense items, and a second list comprised 4 pairs of two syllable nonsense items. A third list comprised 4 pairs of three syllable items (see Hulme et al, 1995 for details of stimuli). The experimenter timed each trial with a stopwatch, and the four scores for each list of items was then converted into a words/second score. This time was used as the measure of speech rate.

Four nonsense words were constructed for use in the paired associate task (see Appendix J). All items were three syllables in length (e.g. canital, jemory, noviet, effergy). Four shapes rated for complexity and associability were used as visual stimuli (Vanderplas & Garvin, 1959). These shapes were selected from the group of 8-point shapes, which were classed as moderately complex. The shapes were the four shapes lowest in associability for this complexity group. One point was given for each correct match. An overall number of correctly remembered pairs was derived from a total of 60 possible correct responses (15 trials x 4 items/block).

6.3.1.3 Procedure

Each child was tested in a quiet place within the school. Each subject received two testing sessions, lasting approximately 15 minutes each. The first session comprised the Basic Reading subsection of the WORD., phoneme deletion test, paired associate learning test, and the list of one syllable items from the speech rate task.

Each child was given 5 practice items on the phoneme deletion test. Corrective feedback was given if practice trials were incorrect. Following this, each child was asked to first listen to a nonsense word spoken aloud by the experimenter. The experimenter then deleted one of the sounds of the nonsense items, after which the child was asked to provide the remainder of the item (e.g. bice, -/b/ = ice).

In the paired associate learning task, each child was shown four abstract shapes and taught the nonsense names of each shape in two learning trials. Participants were asked to repeat the nonword while carefully looking at each abstract shape. Test trials did not begin until each child was able to pronounce the items. The instructions were as follows:

> I'm going to show you four cards. Each card has one shape on it. I have given each shape my own special name. What I'm going to do is show you each card and teach you my special name for each shape. I want you to repeat each name after me. Look carefully at the card I'm showing you.

After the abstract shape/nonword pairs were shown to the children twice, the instructions were as follows: "Now, I'm going to shuffle these cards, and I want to see if you can remember the name that goes with each shape. Ready?"

All four shapes were presented in a random order over 15 trials. Corrective feedback was given to each participant if the attempt was incorrect. If the participants correctly remembered the match, an acknowledgement of the correct match was made. Responses were recorded via DAT and also noted for alter qualitative analysis.

For the speech rate task, each participant practiced each pair of the three speech rate lists 3 times, to find an optimal rate of repetition. Feedback was given during practice trials, and the importance of accuracy was stressed. After all practice trials had been completed, each participant was asked to again repeat each pair 10 times as fast and as accurately as possible.

6.3.2 Results

6.3.2.1 Quantitative Analyses

The means and standard deviations for each variable were calculated for dyslexics and RA controls. The data is shown in Table 6.7.

Table 6.7

Mean scores on phoneme deletion, PA Learning, and speech rate tasks for dyslexics, and RA controls

		Tasks			
Groups	Phoneme Deletion (Max=24)	PA Learning (Max=60)	Rate 1 syllable (w/sec)	Rate 2 syllable (w/sec)	Rate 3 syllable (w/sec)
Dyslexics					
Mean	10.93	23.66	1.96	1.53	1.24
sd	3.84	10.83	.50	.22	.22
RA controls					
Mean	15.66	28.5	1.66	1.19	.97
sd	4.41	11.6	.51	.27	.21

A one-way analysis of variance was carried out on the phoneme deletion data with one between subjects factor, Group (dyslexics; RA controls). This showed a main effect of group ($F(1,26)=8.86$, $Mse=16.84$, $p<.05$). Reading age controls were significantly better at phoneme deletion than dyslexics. A one-way analysis of variance was also carried out on paired associate learning, with one between subjects factor, Group (dyslexics; RA controls). The group differences did not reach significance, although the trend was in the predicted direction ($F(1,25) = 1.24$, $p>.05$).

An analysis of variance was carried out on the speech rate data with one between subjects factor, Group (dyslexics; RA controls) and one within subjects factor, Length, (one syllable nonwords; two syllable nonwords; three syllable nonwords). This showed a main effect of group ($F(1, 25) = 9.17$, $MSe=.19$, $p<.05$), and a main effect of length, ($F(2,50)=38.15$, $MSe=.09$, $p<.001$). There was no significant interaction between group and length($F(2,50)=.23$, $p>.05$). Dyslexics were significantly faster than reading age controls in the speech rate task. The main effect of length revealed that shorter items were spoken faster spoken than longer ($p<.001$) and medium length items ($p<.001$), which in turn were faster than long items ($p<.01$) items for both groups.

The data in present study contrasts with the data in Experiment 1 (see Table 3.3) and Experiment 2 (see Table 3.3), which revealed no group differences on speech rate tasks. The difference in the results between the experiments can be explained by the amount of practice given to the participants prior to the speech rate task. Although the practice items appear to have reduced the number of errors committed by the participants, the participants still made errors. Importantly, dyslexics appear to have increased their speed on the speech rate task as a result of the practice. Thus, administering practice items in the speech rate task did not necessarily ensure that the task was completed without errors. It does, however, appear to give older participants a developmental advantage over the younger participants.

The correlations among paired associate learning and phoneme deletion for dyslexics and RA controls are shown in Table 6.8.

Table 6.8

Correlations between paired associate learning and phoneme deletion for dyslexics and RA controls

	Paired Associate Learning	
Groups	Phoneme Deletion	Speech Rate
Dyslexics	.34	.15
	(.23)	(.60)
RA controls	.72	.47
	(.01)	(.12)

Dyslexics showed a non-significant correlation between paired associate learning and phoneme deletion (r=.34, p=.22), whereas RA controls showed a strong correlation between paired associate learning and phoneme deletion (r=.72, p<.01). This is consistent with the findings of Experiment 5. Moreover, neither of the groups showed a correlation between speech rate and paired associate learning.

A Fisher-z test was conducted on the correlations between speech rate and paired associate learning for dyslexics and RA controls. This analysis was conducted to ensure that the non-significant correlation between speech rate and paired associate learning for RA controls was not a result of the small sample size (N=12). This difference did not reach significance (z=.82).

6.3.2.2 Qualitative Error Analyses

The corpus of errors in the paired associate learning task was examined to determine the types of errors made by each group of participants. Error categories were established, following scrutiny of the transcriptions. Errors were classified as 'intra-list', 'extra-list' or 'no attempt'. First, the 'intra-list' errors included those errors where a child incorrectly named the shape, using another novel word from the list. The 'extra-list' category comprised all those errors where a mis-match was committed between a visual stimulus, and a verbal stimulus not from the list. The 'no attempt' category comprised all the refusals. The proportion of errors committed by each group in each of the categories is shown in Table 6.9.

Table 6.9

Classification of errors made by dyslexics and reading age controls in the paired associate learning task

Errors	Group	
	Dyslexics N=541	RA controls N=372
Intra List Response	.09	.22
Extra List Response	.73	.48
No Response	.18	.30

The proportion of errors shown in Table 6.9 indicate that dyslexics made a greater proportion of extra-list errors than RA controls. In contrast, dyslexics made a smaller proportion of intra-list errors compared to RA controls. This is consistent with the findings of Experiment 5 (see Table 6.4). In Experiments 5 and 6, dyslexics appeared to have greater difficulty learning the response item then in linking the stimulus and response items.

Reading age controls appeared to have greater difficulty *linking* the stimulus and response items, than in learning the response item. However, both groups experienced difficulty learning the response item, as suggested by the high proportion of extra-list errors. Furthermore, the data suggest that RA controls made a greater proportion of 'no attempt' errors than dyslexics. This may have been a consequence of the young age of the reading age controls. Indeed, the reading age controls in Experiment 6 were younger than the reading age controls in Experiments 3 and 5.

6.3.3 Discussion

Interestingly, dyslexics were faster than RA controls on the speech rate task. It appears that the extra rehearsal prior to the speech rate task enabled the dyslexics to articulate the items more quickly than the RA controls. Indeed, dyslexics typically do not show any difficulties with articulatory control tasks (see Chapter 3). However, although dyslexics were able to rehearse quicker than RA controls, both groups made errors on the speech rate task. Furthermore, there were non-significant correlations between paired associate learning and speech rate in both dyslexic and RA control groups. Thus, speech rate was not a predictor of paired associate learning.

Consistent with the results of Experiment 5, there was a dissociation between paired associate learning and phoneme deletion in the dyslexic group. Moreover, there was a strong correlation among the two variables in the RA control group. Thus, it appears that dyslexics are consistently poor on phonological awareness tasks, while their ability to associate visual-verbal pairs is less systematically impaired. Plausibly, the level of their performance is a consequence of the severity of the underlying phonological deficit.

Finally, dyslexics and RA controls were comparable in their performance on the paired associate learning task. Thus, we failed to replicate a deficit in paired associate learning for the dyslexic group. The error analyses of the PA learning task showed that RA controls committed significantly more 'intra-list' errors, than the dyslexics. In contrast, dyslexics committed significantly more 'extra-list' errors than the RA controls. Consistent with the results of Experiment 5, this suggests that the dyslexics had difficulty in learning the response item in the PA Learning task. Thus, the results of the paired associate learning tasks in Experiments 3, 5, and 6, are equivocal about whether dyslexics suffer from a deficit in paired associate learning.

6.4 A Meta-Analysis of the Data from Three Paired Associate Learning Experiments

6.4.1 Comparative Data Analysis

Since the performance of dyslexics relative to RA controls differed between Experiment 3, 5, and 6, this warranted scrutiny of the tasks employed to assess the possible reasons for the divergence of the results. Unfortunately, only a subset of the subjects participated in all three studies, so direct comparisons were not appropriate. It was decided as an alternative to examine the factors of the experiment that may have accounted for differences, focusing on the data from dyslexics and RA controls.

In Experiment 3, the paired associate learning task comprised four pictures of abstract paintings (3 in. x 5 in.), each to be paired with a nonword (see Appendix E). There were two one syllable nonwords (e.g. lazz, vob) and two three syllable nonwords (e.g. lasious, noliet). Participants were presented with one of two versions of the visual-verbal pairs in the learning trials. Half of the children were taught the first version of visual-verbal pairs, and the remaining participants the second order of pairs. This was to ensure that differences in the salience of visual-verbal pairs would not bias the results (see Chapter 4 for details).

In Experiment 5, the paired associate learning task comprised four abstract shapes, each paired with a nonsense name (e.g. stosp, taith, meferal, balio). Similarly, in Experiment 6, the paired associate learning task comprised abstract shapes each paired with a different nonsense word (e.g. canital, jemory, noviet, effergy) (see Appendix I). In Experiment 5 and 6, four shapes rated for complexity and associability were used as visual stimuli (Vanderplas & Garvin, 1959) (see Chapter 5 and 6.2 for details).

Thus, in Experiment 3, the visual stimuli were more concrete, and potentially easier. Indeed, there is some evidence to suggest that the ability to recall the response item depends on the salience of the stimulus item (Paivio & Yarmey, 1966). The association between stimulus and response items has been shown to be strongest when the stimulus item is a picture, and the response item a word (Dilley & Paivio, 1968). The picture functions as a 'peg', facilitating the association of the stimulus to the response item (Paivio & Yarmey, 1966).

Furthermore, the nonword response items were more difficult in Experiments 5 and 6, compared to Experiment 3. Possibly, the increased response item difficulty may have accounted for the lack of group differences in Experiment 5. Plausibly, RA controls found learning the response items difficult, thereby decreasing the sensitivity of task to their ability to link the verbal and visual stimulus. Alternatively, dyslexics may have found learning the response items in Experiment 5 and 6 more difficult, reducing the sensitivity of the task to their ability to link the visual and verbal stimuli. A third possibility is that the increased response item difficulty may have affected the performance of both groups in Experiment 5 and 6.

A comparison of the age of the reading age control groups in Experiments 3, 5, and 6 revealed that the children in Experiment 3 (9;3) were approximately 9 months older than the children in Experiment 5 (8;6), and 11 months older than the children in Experiment 6 (8;2). Overall then, it seems to suggest that the RA controls in Experiment 3 were better able to cope with the demands of the paired associate learning task, because of their advanced age, relative to the other two groups.

The percent correct on paired associate learning in Experiment 3, 5, and 6 for dyslexics and RA controls is shown in Table 6.10.

Table 6.10

Percentage correct on paired associate learning in Experiment 3, 5 and 6 for dyslexics and RA controls.

Groups	Percent Correct		
	Experiment 3 (Max=40)	Experiment 5 (Max=80)	Experiment 6 (Max=60)
Dyslexics	.54	.40	.39
RA controls	.66	.44	.48

As can be seen in Table 6.10, dyslexic and normal readers correctly learned a higher proportion of the paired associates in Experiment 3, than in Experiments 5 and 6. In Experiment 5, there was a downward trend in the performance of both groups. Indeed, the discrepancy between the proportion of pairs correctly associated, decreased between dyslexics and normal readers in Experiment 5, compared to Experiment 3. In Experiment 6, dyslexics performed comparably to Experiment 6, while normal readers improved marginally. Moreover, the discrepancy between the performance of dyslexics and normal readers increased in Experiment 6, compared to Experiment 5.

Thus, the trends in the data suggest that both groups performed better in Experiment 3, compared to the other experiments. Furthermore, despite the fact that the performance of the participants in Experiments 5 and 6 was generally worse, there was still a trend for dyslexics to do more poorly than RA controls. It was therefore decided to conduct an analysis of the effect sizes in the three experiments to investigate whether the reason the dyslexics and RA controls difference failed to reach significance was due to low statistical power in the latter experiments (see Table 6.11).

Table 6.11

Statistical power analysis for PA learning in Experiments 3, 5, and 6

Experiments		Groups			
		Dyslexics	RA controls	Effect Size (γ)	Power (.05)
Experiment 3	Mean	21.46	26.26	.70	.58
(Max=40)	sd	5.91	6.85		
Experiment 5	Mean	31.61	35.33	.21	<.17
(Max 80)	sd	14.05	17.81		
Experiment 6	Mean	23.66	28.5	.42	.20
(Max=60)	sd	10.08	11.6		

In Experiment 3, the group difference was significant at $\propto$=.05, with an effect size of γ=.70. The sample size N was 15. To assess the power, the equation ($\delta=\gamma\cdot(N/2)$) (Howell, 1982, p.160-161) was used. The value of the power of Experiment 3 was calculated at δ=1.91 (power at .05=.48). This level of power was set for Experiments 5 and 6, in order to assess the sample size needed to reach significance. First, the effect sizes for Experiments 3, 5 and 6 were calculated using the equation ($\gamma = \mu_1 - \mu_2/\sigma$). The value calculated for delta in Experiment 3 (δ=1.91) was used to calculate the number of subjects required to achieve a significant result in Experiments 5 and 6 ($1.91 = \gamma(\sqrt{N/2})$).

This analysis revealed that 165 subjects were needed to achieve significant group differences in Experiment 5, with 41 subjects required to achieve significance in Experiment 6. Thus, the small N size in Experiments 5 and 6 precluded significant group differences, although the results of Experiment 3 suggest a paired associate learning deficit in dyslexics, relative to RA controls.

6.4.2 Discussion

Taken together, the results suggest that dyslexics do suffer from a deficit in paired associate learning. Importantly, the power analyses showed that significant group differences would have been obtained in Experiments 5 and 6 given larger sample sizes. Moreover, the subjects in Experiment 3 were older than the subjects in Experiments 5 and 6. Reasonably, they may have been better able to cope with the task demands of paired associate learning. Thus, it is suggested that small sample sizes and the age of the RA controls contributed to the contradictory findings in the paired associate learning experiments.

6.5 Summary and Conclusions

Taken together, the results of Experiment 5, 6, confirm previous findings in the literature of phonological awareness impairments in dyslexic children, with the performance levels of the dyslexic children falling below younger RA controls. Furthermore, the results show that dyslexics may also have impairments in phonological learning. The results of Experiment 3, 5, and 6 appear equivocal, as to a deficit or a delay pattern in dyslexic children. However, the meta-analysis of these experiments suggests that task difficulty and subject numbers may have masked a deficit in Experiment 5 and 6. So, together with a greater proportion of extra-list errors, dyslexics do seem to show a disorder of paired associate learning when compared to reading age controls.

Overall, the findings are consistent with the phonological deficit hypothesis of dyslexia. As mention previously (see Chapter 3), phonological representations are poorly specified in dyslexic readers. This constrains their phonological awareness and paired associate learning abilities, in addition to their verbal memory and speech rate abilities.

Chapter 7

General Conclusions and Theoretical Implications

7.1 Summary of the Findings

The aim of the thesis was to investigate the verbal learning, verbal memory, phonological awareness, and reading skills of normal reading and dyslexic children. The primary tenet of this thesis is that dyslexic children suffer from a core phonological deficit. That is, dyslexic children's reading and spelling development deviates from that of normal readers as a consequence of poorly specified underlying phonological representations. Moreover, the pervasiveness of the phonological deficit depends upon the degree of underspecification of the phonological representations.

All of the dyslexic children who participated had been identified by previous testing carried out by the local education authority and/or special needs teachers. In addition, the dyslexic children were re-tested on standardised reading and nonverbal ability tests to ensure that they were reading at least two years behind their chronological age, but were age appropriate on nonverbal ability tests.

The reading-level matched design was used in each experiment, with the exception of Experiment 4 which was a normative study. Each dyslexic was matched within six months of their reading age with a reading age control, and also to within six months of their chronological age with a chronological age control, except in

Experiment 6. All the children in the reading age control, and the chronological age control groups were judged as reading age appropriately by their classroom teachers.

Experiments 1 and 2 focused on verbal short term memory processes. Dyslexics as well as normally developing readers showed robust effects of lexicality and length in the verbal short term memory task in both experiments; word items were always better recalled than nonword items, and shorter items were always better recalled than longer items. Moreover, all participants showed a strong relationship between memory span and speech rate processes. Unexpectedly, dyslexic readers did not show a decrement in memory span or speech rate performance in Experiment 1 compared to normal readers. Error analyses conducted on the speech rate errors made by all three groups of participants revealed that dyslexics made more errors than CA controls. Thus, measured speech rate appeared to be an overestimation of rehearsal speed for dyslexic readers, leaving open the possibility that they rely more on support from long term memory for satisfactory performance.

Experiment 2 was a replication and extension of Experiment 1. In this experiment, dyslexics remembered fewer items than CA controls in the memory span task, although their performance was comparable to that of younger RA controls. Similar to Experiment 1, there were no group differences in the speech rate recorded for the three groups. However, once again, the dyslexic readers made approximately twice the number of word and nonword errors as the CA controls, although still comparable in performance to the RA controls. Taken together, Experiments 1 and 2 are in line with the hypothesis that dyslexic readers have phonological processing deficits. These deficits were seen most clearly as affecting accuracy on the speech rate tasks. However, there was no association between speech rate and articulatory processes in the dyslexic group, indicating that their poor speech rate performance was not a consequence of articulatory control difficulties. In addition, in Experiment 2, dyslexics showed a developmental delay in verbal short term memory abilities.

Experiment 3 investigated the verbal learning skills of normal and dyslexic readers on a paired associate learning task. In this task, the children were required to associate a novel visual stimulus (stimulus item) with a novel verbal stimulus (response item). The results showed that dyslexics were significantly poorer than both CA and RA controls. Error analyses were carried out on the errors made by each of the participants on the paired associate task. Although the dyslexic readers committed significantly more errors overall, the three groups did not differ in the proportion of different error types made. All of the groups were most likely to make errors, mis-matching the visual stimulus with a verbal stimulus not on the list.

Thus, Experiment 3 revealed that the dyslexic readers had a deficit in learning verbal paired associates. However, it was not possible to establish if the locus of the dyslexic children's difficulty was in learning the association between the stimulus and response, learning the response item itself, or a combination of the two possibilities. Moreover, the finding left unanswered the relationship between paired associate learning and other phonological skills deemed to be casually related to reading, and reading disability.

Experiment 4 was conducted to investigate the relationship of paired associate learning, phonological awareness and reading in a cross-section of normal readers. The children were administered two phonological awareness tasks (e.g. phoneme deletion; rhyme oddity), a test of nonword reading, a test of memory for words and nonwords and a paired associate learning task. Importantly, the results showed that paired associate learning contributed unique variance to reading skill, separate from phonological awareness. Furthermore, phonological awareness and paired associate learning were highly correlated. Indeed, phonological awareness made a unique contribution to paired associate learning ability. In light of this evidence, it seemed plausible that the dyslexics deficit in paired associate learning should be closely linked with their deficit in phonological awareness. This idea was tested in Experiments 5 and 6.

Experiment 5 followed the same procedure as Experiment 4, investigating the relationship between reading and paired associate learning, verbal short term memory, phonological awareness, and reading skill in dyslexics, RA and CA controls. As predicted from previous research, the dyslexic readers were worse on tests of phonological awareness than both CA and RA controls. However, in this experiment, they were poorer at paired associate learning that CA controls, but performed at the same level as their reading age controls. Nonetheless, a qualitative comparison of their performance with that of the younger controls revealed differences; the dyslexic readers more often mis-remembered the response items than the controls, who tended to mis-match the visual stimulus with an incorrect verbal response from within the set. Furthermore, there was a striking difference between the performance of the dyslexics and both sets of controls in the relationship between phonological awareness and paired associate learning. Interestingly, dyslexic readers showed a dissociation between phonological awareness and paired associate learning skills whereas normal readers showed a moderate correlation between these skills. Furthermore, dyslexics showed greater variation in their performance on paired associate learning compared to their performance on phonological awareness tasks (e.g. phoneme deletion; rhyme oddity).

The aim of Experiment 6 was to adjudicate between the results of Experiment 3 which showed a deficit in paired associate learning for dyslexics in relation to reading age controls, and Experiment 5, which showed a deficit only in relation to CA controls. In addition, a secondary aim was to readdress the speech rate findings of Experiment 1 and 2. As discussed above, dyslexic readers did not show a difference in speech rate performance from CA or RA controls. However, they made a significant number of errors when completing these tasks. The aim here was to reduce error rates by increasing practice, in addition to encouraging monitoring behaviour. Second, the aim was to investigate the relationship between phonological awareness, speech rate performance, and paired associate learning.

Thus, dyslexics and reading age controls were administered phoneme deletion, paired associate learning, and speech rate tasks. The speech rate task was altered from Experiments 1 and 2, in that each participant received training on the nonword pairs to be used in the task. The aim was to ensure that all the participants correctly pronounced the items during the timed speech rate task. This procedure was successful and enhanced the speed of the dyslexics. Furthermore, practice reduced the errors made during the speech rate task.

As in Experiment 5, the dyslexic readers performed at a similar level to reading age controls on the paired associate learning task. Once again, they showed a strong dissociation between phoneme deletion and paired associate learning, whereas normal readers showed a strong correlation between the two measures. Speech rate was not correlated with paired associate learning for either group. Similar to the results of Experiment 5, dyslexic readers committed significantly fewer intra-list, and a significantly greater proportion of extra-list errors in paired associate learning compared to reading age controls. This suggests that dyslexics had difficulty in learning the response item of the paired associates.

Furthermore, a meta-analysis was conducted, examining the performance of dyslexics and younger normal readers on the paired associate learning task in Experiments 3, 5, and 6. The results suggest that both groups found Experiments 5 and 6 more difficult, than Experiment 3. Plausibly, the younger age of the normal readers in the latter experiments may have contributed to the comparable performance of the two groups. Alternatively, the visual and verbal stimuli were altered in the latter experiments, possibly contributing to the task difficulty in Experiments 5 and 6. Importantly, the analyses showed that the small sample size in Experiment 5 and 6 precluded the possibility of group differences between dyslexic readers and younger, normal readers. Taken together, the results suggest that dyslexic do show a deficit in paired associate learning, compared to younger normal readers.

7.2 Theoretical Implications

7.2.1 Reading and Phonology

The experimental results presented here have several theoretical implications for the reading process in normally developing children. First, there was a strong relationship between phonological awareness and reading. Indeed, in Experiment 4 (Chapter 5), phonological awareness contributed unique variance to the prediction of reading skill. Moreover, the results of Experiment 6 showed a strong relationship between phonological awareness measures and reading skill in normal readers children. This is in line with overwhelming evidence implicating the important role of phonological awareness in later reading development (Wagner & Torgesen, 1987; Goswami & Bryant, 1990).

An important theoretical issue in the literature concerns the structure of underlying phonological skills. Some have argued for a unitary structure of phonological awareness (Stanovich et al., 1984) while others have argued for a multi-component structure comprising phonological awareness (Yopp, 1988; Wagner, et al., 1993). One of the most influential theories about the structure of underlying phonological skills was advanced by Goswami and Bryant (1990). As mentioned in Chapter 1, their argument stresses the importance of different levels of phonological awareness. Importantly, they argue that it is the sub-syllabic units of onset and rime which are causally related to reading development. Smaller phonological units such as phonemes, develop partly as a consequence of learning to read. Thus, there are at least two separate independent sub-skills comprising phonological awareness: rhyme and phonemic segmentation.

The results of the present research are relevant to this debate, as both measures of rhyme and phoneme segmentation were administered. The results of Experiment 4 (Chapter 5) revealed that both rhyme oddity and phoneme deletion tasks were correlated with reading skill. Moreover, they both made independent contributions to reading skill, consistent with Goswami and Bryant (1990) and Muter et al., (1997). Unexpectedly, both rhyme oddity and phoneme deletion accounted for approximately equal amounts of variance in reading skill. This contradicts previous studies which showed that rhyme oddity was a weaker predictor of reading skill than phonemic segmentation tasks (Nation & Hulme, 1997; Muter et al., 1997). However, it is important to note that the children here were much older.

Furthermore, there is some evidence to suggest that phonological awareness is a stronger predictor of reading skill than verbal memory and speech rate. McDougall et al. (1994) showed that phoneme deletion and rhyme made independent contributions to reading skill. In contrast, verbal memory span did not make a unique contribution to reading skill after speech rate had been accounted for. McDougall et al., (1994) suggested that speech rate subsumed much of the variance accounted for by verbal memory span. Indeed, they made the radical suggestion that speech rate was another phonological measure, which was closely related to reading ability. Similarly, the results in the research presented here revealed that memory span contributed unique variance to reading skill only when entered in before phonological awareness measures. This suggests that phonological awareness, as measured by phoneme deletion and rhyme oddity, subsumed much of the variance contributed by verbal memory.

However, the results of McDougall et al., (1994) showing that speech rate and reading skill were closely related, is not supported by the present research. In their study, speech rate was moderately correlated with reading ability, while verbal memory span was only weakly correlated. Moreover, speech rate accounted for unique variance in reading skill, while memory span did not account for unique variance, after speech rate had been accounted for. Thus, McDougall et al., (1994) proposed that verbal memory span was simply a 'useful predictor of reading skill to the extent that it taps individual differences in speech rate' (p.129). They suggested that speech rate was an index of the speed and efficiency with which the underlying phonological codes were activated.

In the present experiments, speech rate was not correlated with phonological awareness tasks or reading ability. Indeed, verbal memory span, although a weak predictor of reading ability, was more strongly associated with reading ability than was speech rate. Importantly, errors were examined qualitatively in the speech rate task. The results showed that a qualitative approach was sensitive to the specificity of the underlying phonological representations. This is in contrast to the speed at which the task was completed, which showed no differences between normal and dyslexic readers.

Reasonably, the speed at which the speech rate task is completed, is largely constrained by output processes. However, dyslexic children do not typically show any difficulty with articulatory control (see Chapter 3). Thus, it is perhaps unsurprising that the dyslexic readers performed similarly to normal readers on this task. Thus, the results of the research presented here, showed that a speeded speech rate measure did not tap the specificity of the underlying phonological representations, as suggested by McDougall et al., (1994). Importantly, the findings do suggest that it is the error rate in the speech rate task which elucidates the specificity of the underlying representations.

For the first time, it was shown that phonological learning (e.g. paired associate learning) made a unique contribution to reading ability. Paired associate learning contributed approximately equal amounts of variance to reading skill as did measures of phonological awareness. Importantly, phonological learning and phonological awareness were closely related. Reasonably, phonological learning and phonological awareness depend on the same underlying resource; phonological representations.

In contrast, the results of Experiment 4 (Chapter 5) clearly showed that paired associate learning was a stronger predictor of reading ability, than verbal memory span. Indeed, verbal memory span and paired associate learning were not significantly associated. Furthermore, the results of Experiment 6 (see Chapter 6) showed that paired associate learning was not significantly related with measures of speech rate. This finding supports the view that tasks which share similar processing demands (e.g. phonological awareness, paired associate learning) are more closely associated than tasks which share fewer processing demands (e.g. verbal short term memory, paired associate learning; verbal short term memory, phonological awareness).

Finally, this finding has important theoretical implications for the reading system of normal readers. The independent contributions of phonological awareness and phonological learning (e.g. paired associate learning) suggest that there are two mechanisms involved in setting up a normal reading system. Arguably, one system is tapped by phonological awareness, and the second, by paired associate learning.

7.2.2 Dyslexia, Phonological Processing, and Reading Skill

Theories of reading acquisition have tended to focus on the role of phonological skill in the development of alphabetic learning. In particular, phonological awareness has been shown to be a strong predictor of reading achievement even when age and IQ are controlled. The corollary of this is that dyslexic children show poor phonological awareness, normally considered to be a consequence of poorly specified phonological representations (Snowling, 1980; 1982; Manis et al., 1993; Bruck, 1992). The findings of the present research support this theoretical position.

Indeed, the results of the Experiments 5 and 6 (see Chapter 6) showed that dyslexics were impaired in their phonological awareness skills, compared to normal readers. This supports the notion that dyslexics have difficulty in interrogating underlying phonological representations explicitly. Moreover, dyslexics displayed nonword reading impairments compared to younger readers. Nonword reading taps decoding and blending skills, sharing similar processing demands to word reading. A deficit in this task is further confirmation that dyslexic children experience difficulties with phonological awareness; a consequence of under-specified phonological representations.

A second theoretical implication of the present research concerns verbal short term memory. The available research into dyslexics' verbal short term memory abilities is equivocal about whether the difficulties arise from a primary deficit within the working memory system, or as a result of poorly specified underlying phonological representations that need to be activated during memory tasks (Jorm, 1983). The results of the experimental research presented here show that memory span performance was comparable to that of younger readers. They benefited from phonological and morphological information as did normal readers. Moreover, they benefited from a long term memory contribution This suggests that the mechanisms involved in accessing phonological representations for verbal short term memory are similar in normal and dyslexic readers. Plausibly, whilst the framework for accessing phonological representations in dyslexic readers is similar to that of normal readers, the phonological representations accessed in the verbal memory task are poorer in quality.

Furthermore, McDougall et al., (1994) suggested that the speech rate task was an index of the speed of access to underlying representations. In contrast, the results of the present research showed that dyslexic readers did not differ from normal readers in the speed of the task (see Chapter 3). Indeed, when given practice prior to the speech rate task, dyslexics were faster than younger RA controls (see Chapter 6). At first sight, this is contradictory to the notion that dyslexic readers have under-specified phonological representations, which impair their phonological processing abilities. However, a qualitative analysis of the speech errors revealed that dyslexic readers made more errors than normal readers. Thus, the findings from the error analyses suggest that the speed at which the task is completed does not reflect the quality of the underlying representation.

Furthermore, the results of the articulatory control measures in Experiment 1 (see Chapter 3) showed that dyslexics did not have articulatory control problems. Given that the speech rate task has a strong output component, it is unsurprising that the dyslexic readers were not impaired on the speed of this task. Thus, the results suggest that impairments of verbal short term memory and speech rate co-occur as a consequence of poorly specified phonological representations.

Finally, the present research has theoretical implications for the reading system of the dyslexic reader. There is some evidence to suggest that dyslexics have difficulty learning visual-verbal paired associates (Vellutino et al., 1975; Vellutino et al., 1995; Wimmer et al., 1997). Paired associate learning requires creating novel phonological representations, and linking them with a visual stimulus. The results of the present research showed that dyslexics were worse than their peers on a visual-verbal paired associate learning task. Indeed, dyslexic readers were worse than even younger readers on a paired associate learning task in Experiment 3 (see Chapter 4). Conversely, the findings of Experiments 5 and 6 showed that dyslexic and younger normal readers performed comparably. Thus, the results of the present research are equivocal about a deficit or a delay in paired associate learning.

However, one account of the available research is that dyslexics do have an impairment in paired associate learning. Tapping this deficit is dependent upon factors such as the construction of the paired associate learning task, and the number of participants taking part in the experiment. Indeed, the meta-analysis of the paired associate learning experiments showed that given larger participant numbers, dyslexics would have been worse than younger readers. Importantly, finding a deficit pattern is dependent upon the severity of the phonological deficit of the dyslexic reader.

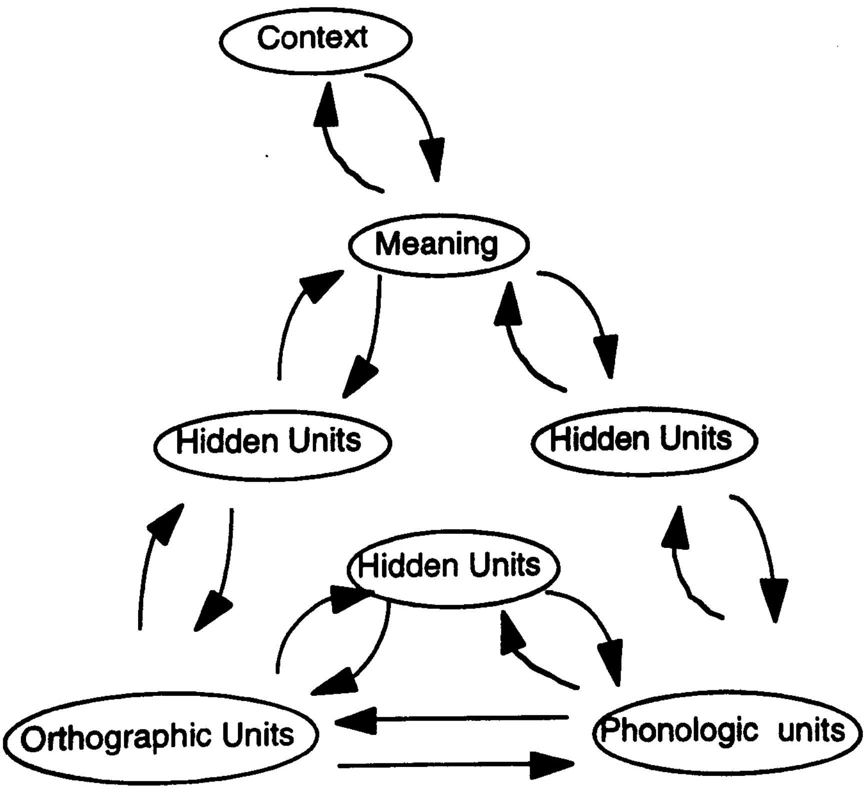
Theoretically, it is suggested that phonological awareness and phonological learning tap two separate mechanisms in the reading system. Indeed, the dissociation between phonological awareness and paired associate learning support this view (see Chapter 6). Furthermore, we suggest that both mechanisms are impaired in dyslexic readers, as they both rely on underlying phonological representations to a greater or lesser extent.

7.2.3 A Connectionist Account

Taken together, the results of the present research pertaining to the reading system of normal reading and dyslexic children are well accounted for within a connectionist framework. Learning to read involves learning associations between letter strings and spoken words. This aspect of reading is well captured by current connectionist models of the reading process. One of the most influential connectionist models was proposed by Seidenberg and McClelland (1989) (see Figure 7.1). This model comprises three sets of units: orthographic input units, and phonological output units. These two sets of units are connected via a third set of 'hidden' units.

Figure 7.1

Connectionist Framework proposed by Plaut et al., (1996) after Seidenberg & McClelland (1989)



An important feature of Seidenberg and McClellands' model and others like it, is that the orthographic and phonological units of a word are coded by patterns of distributed activation over a set of representational units. The strengths of the connections between the units are a function of 'training' the model over a period of time. Thus, the model 'learns' rules in the absence of explicit rules in the system. In short, the connectionist framework conceptualises reading as an interactive process in which orthographic inputs are mapped on to phonological output units.

In later versions of this model (e.g. Plaut, McClelland, Seidenberg & Patterson, 1996) an implemented semantic pathway interacts with the phonological pathway to bring about reading (see Figure 7.1). In this model, phonological processes deal with orthography to phonology mappings, and semantic processes with semantic, phonologic, and orthographic representations. The routes are assumed to change in the degree of importance throughout the course of reading development. According to Plaut et al., the phonological pathway is most important early on in reading development; resources are dedicated to establishing orthography to phonology links. The semantic pathway becomes more important as reading development proceeds. Finally, in the later stages of reading development Plaut et al. (1996) propose that semantic and phonologic pathways interact, eventually resulting in a 'division of labour' between the pathways. That is, the resources from the pathways are reallocated as a function of reading development.

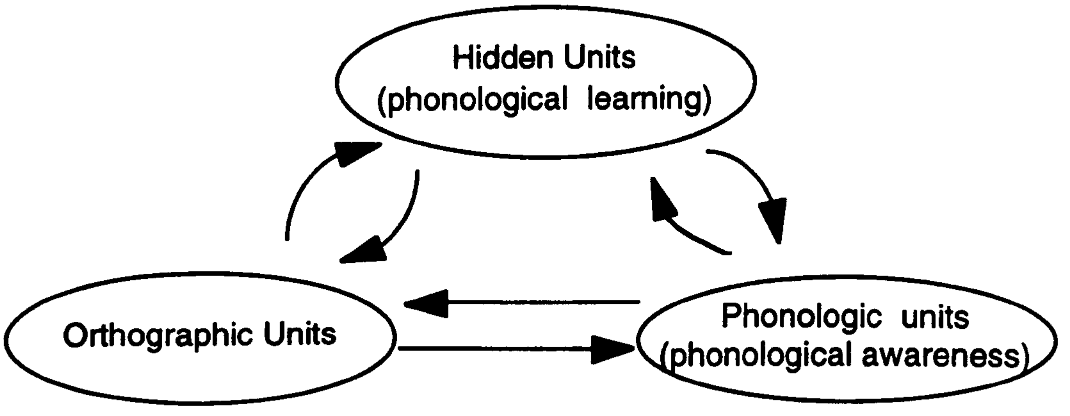
In a connectionist system, learning to read efficiently depends on the specificity of the phonological representations. Particularly relevant to the issue of learning to read is how the information embodied in the connections generalises. This has been show to depend on the nature of the phonological codes in the system. Brown (1997) compared the ability of Seidenberg and McClellands' (1989) and Plaut et al.'s (1996) models to read regular and irregular words, and nonwords. The results showed that the two models produced different degrees of nonword reading impairments, as a direct result of the specificity of the phonological representations entered into the model. Seidenberg and McClelland implemented triple-based representations of words. For instance, the word HAVE was represented by _HA, HAV, AVE, VE_ (the _ representing the word boundary) (cf. Brown, 1997). In contrast, Plaut et al., (1996) implemented separate units representing each letter or grapheme. Thus, the Plaut et al., (1996) model implemented representations at the phonemic level; Seidenberg and McClelland implemented representations at the rime level.

Thus, models trained with coarse phonological representations are less effective in learning a corpus of words, and display impaired nonword reading (Seidenberg & McClelland, 1989). These models more closely simulate the behaviour of dyslexic readers, than models which implement fine grained phonological representations (Plaut et al., 1996). However, the integrity of the phonological representations is only one facet of learning. Also important, is the network's capacity to learn the association between orthographic and phonologic representations, or, the orthography to phonology 'link'. This general processing resource is instantiated in connectionist models as the 'hidden units'.

Reasonably, the processes involved in paired associate learning are closely analogous to the learning processes required to set up a reading system. This task involves linking, or learning to associate, a novel verbal stimuli to a novel visual stimuli. The results of the experiments reported here suggest a second mechanism required in setting up an effective reading system; that is, phonological learning (see Figure 7.2). Arguably, phonological awareness taps underlying phonological representations (e.g. phonological units), and paired associate learning, the ability to link orthography and phonology (e.g. hidden units). In normal reading development, phonological representations underlie orthographic learning. Arguably, this learning is also facilitated by capacity

Figure 7.2

Diagram conceptualising the two mechanisms involved in setting up a normal reading system.



Furthermore, the results of the present research suggest that dyslexics have an impairment in both phonologic units (e.g. phonological awareness) and hidden units (e.g. paired associate learning). Plausibly, some dyslexics with milder phonological problems may be able to develop associations between larger phonological units (e.g. syllables, words) and whole-word shapes whilst still being unable to perform the segmental operations that are tapped by phonological awareness tasks. Other dyslexic readers with more pervasive difficulties, may show various phonological deficits (e.g. phonological awareness, verbal short term memory, and phonological learning).

Speculatively, the former dyslexic sub-type may be akin to surface or reading delayed dyslexia; the latter to phonological dyslexia. Thus, for dyslexics, the ability to create phonological representations is impaired, as is the ability to 'hook up' orthography and phonology. However, this 'hook up' is not as severely impaired as the ability to create phonological representations because it does not necessarily depend on fine grained phonological representations.

7.3 Limitations and Future Research

One limitation of the present research pertains to the memory span data in Experiment 1 and 2. It would have been beneficial to record the data for further error analysis. Plausibly, further qualitative analysis of the memory span data would have revealed whether the dyslexics appeared less severely impaired in the quantitative data than the qualitative data, similar to the pattern of findings in the speech rate task.

A second limitation of the present research was the inclusion of only one type of paired associate learning task; novel word and novel visual stimuli. Although previous experiments have shown that dyslexics are not impaired on visual-visual, or nonverbal-visual associations, these experiments have typically not included reading age controls. It is important to further investigate the performance of and normal readers on various types of paired associates, (e.g. visual-visual; visual-verbal; visual-nonverbal; and verbal-verbal) to confirm whether the specific learning difficulty lies with creating representations for the verbal stimuli, remembering the visual stimuli, or, in the link between the two stimuli.

Furthermore, if the learning mechanism involved in paired associate learning is affected by the severity of the underlying phonological impairment, it is important to investigate the performance of children classified as surface and phonological dyslexics on paired associate learning tasks. In the studies presented here, the group of dyslexics had severe phonological impairments, and were thus more likely to be classified as phonological dyslexics. One would predict that surface dyslexics would show better performance than the phonological dyslexics. Moreover, it would be interesting to investigate the development of the learning mechanism in a longitudinal study. A future study might include the two subgroups of dyslexics, matched with reading age and chronological age matched normal readers. Plausibly, the surface dyslexics would show a developmental delay pattern compared to a deficit pattern in the phonological dyslexic group.

Finally, the data suggests that task difficulty affects the level of performance on paired associate learning. In the present studies, the associability of the visual stimulus, the number of trials to completion, and the syllable length of the verbal stimuli were manipulated. While syllable length did not appear to affect performance between the groups, it was difficult to determine the effects of the salience of the visual stimuli.

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APPENDICES

Appendix A

Memory Span and Speech Rate Stimuli

Experiment 1

Memory Span and Speech Rate Word Items	Memory Span and Speech Rate Nonword Items
One Syllable Words	*One Syllable Nonwords*
Greece/school	bim/dof
stoat/maths	fot/gug
zinc/mumps	mab/sep
scroll/switch	pid/zog
Three Syllable Words	*Three Syllable Nonwords*
botany/Mexico	ballem/crepog
bulletin/leprosy	giffel/maffow
calcium/radio	grelub/teggid
nursery/gorilla	swijit/tafost
Five Syllable Words	*Five Syllable Nonwords*
aluminium/hippopotamus	arellum/bepavit
periodical/refrigerator	gossikos/jodazum
tuberculosis/Yugoslavia	monosip/tushibon
physiology/university	zegglepim/muttasek

Appendix B

One Syllable Memory Span and Speech Rate Stimuli

Experiment 2

One Syllable Word Items	One Syllable Nonword Items
High Phonological Neighbourhood Items	*High Phonological Neighbourhood Items*
post/cold	dost/jold
list/job	bist/pob
game/test	vame/yest
bed/hope	med/lope
Low Phonological Neighbourhood Items	*Low Phonological Neighbourhood Items*
cost/youth	yost/douth
pure/brown	bure/spown
land/month	gand/wonth
voice/jazz	roice/vazz

Appendix C

Three Syllable Memory Span and Speech Rate Stimuli

Experiment 2

Three Syllable Word Items	Three Syllable Nonword Items
Derivationally Affixed	*Derivationally Affixed*
difference/physical	sifference/phymical
officer/natural	onnicer/vatural
manager/governor	macager/tovernor
national/various	gational/vasious
Non-Derivationally Affixed	*Non-Derivationally Affixed*
memory/attitude	jemory/affitude
soviet/company	noviet/lompany
character/energy	tharacter/effergy
possible/capital	pommible/canital

Appendix D

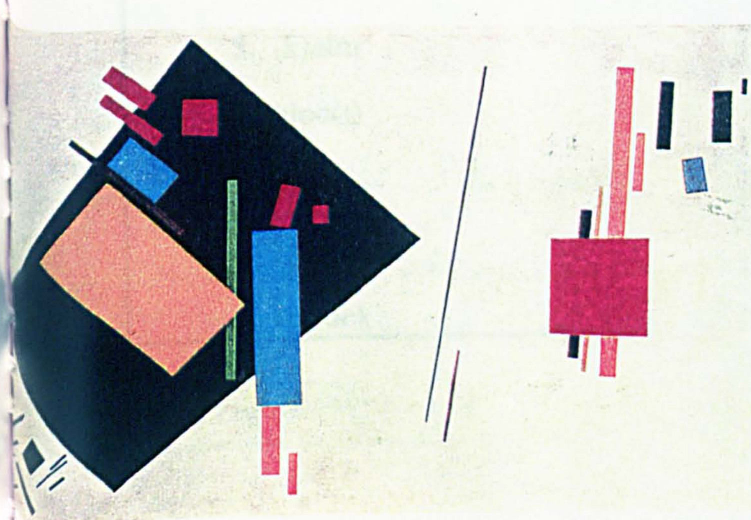
Paired Associate Learning Stimuli (first order)

Experiment 3

(actual size 3 in. x 5 in.)

LAZZ

LASIOUS



VOB

NOLIET

Appendix E

Phoneme Deletion Task

<u>Practice</u>

1. pin(t)
2. (t)ink
3. bar(p)
4. p(r)ot
5. noa(s)t
6. t(r)one
7. grin(t)
8. p)lime

<u>Test</u>

1. (b)ice
2. toa(b)
3. (b)arch
4. tea(p)
5. (k)elm
6. bloo(t)
7. jar(l)
8. (g)lamp
9. (b)rock
10. (b)rock
11. s(t)ip
12. hi(f)t
13. star(p)
14. c(r)oal
15. (f)rip
16. hil(f)
17. cro(t)s
18. c(l)art
19. bir(l)d
20. fors(k)
21. s(p)low
22. (s)trail
23. (b)eel
24. cloo(f)

Appendix F

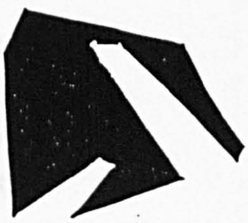
Rhyme Oddity Task

1) job	mob	rob	*knock*
2) had	lad	mad	*pack*
3) *bid*	pig	dig	wig
4) *nod*	rob	mob	job
5) big	wig	*pit*	dig
6) *mad*	gap	wrap	tap
7) *rib*	kick	lick	pick
8) pit	*sick*	fit	hit
9) pad	bad	*lap*	sad
10) cap	tap	map	*sack*
11) cop	hop	top	*mob*
12) *lap*	hat	rat	sat
13) log	*job*	dog	fog
14) pad	had	*bat*	mad
14) lick	*kid*	pick	tick
16) *log*	hot	rot	pot
17) back	sack	pack	*rap*
18) lip	dip	*hit*	chip
19) job	knob	*rot*	sob
20) got	hot	cot	*knob*
21) sock	lock	rock	*dog*
22) bag	*tap*	rag	sag
23) rob	*mop*	knob	job
24) lip	*dig*	ship	tip
25) knob	*jog*	rob	mob
26) lid	kid	*rib*	hid

Appendix G

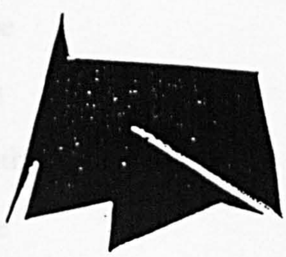
Paired Associate Learning Stimuli

Study 4 and Experiment 5



STOSP

TAITH



MEFERAL

BALIO

Appendix H

Memory Span Stimuli

Study 4 and Experiment 5

Word Stimuli	Nonword Stimuli
1. post	1. dost
2. list	2. bist
3. bed	3. med
4. cold	4. jold
5. test	5. yest
6. hope	6. lope
7. cost	7. yost
8. youth	8. douth
9. pure	9. bure
10. brown	10. spown
11. land	11. gand
12. month	12. wonth
13. voice	13. roice
14. jazz	14. vazz

Appendix I

Speech Rate Stimuli

Experiment 6

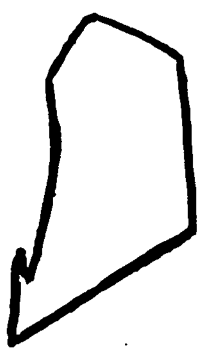
Memory Span and Speech Rate Nonword Items
One Syllable Nonwords
bim/dof
fot/gug
mab/sep
pid/zog
Three Syllable Nonwords
ballem/crepog
giffel/maffow
grelub/teggid
swijit/tafost
Five Syllable Nonwords
arellum/bepavit
gossikos/jodazum
monosip/tushibon
zegglepim/muttasek

Appendix J

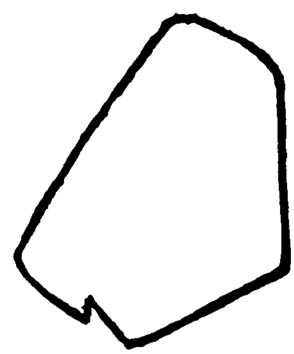
Paired Associate Learning Stimuli

(shapes were blue in colour)

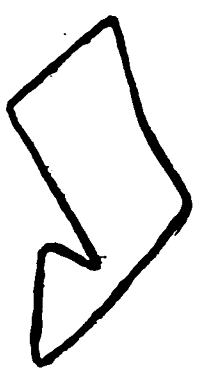
Experiment 6



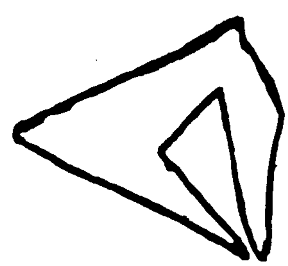
JEMORY



NOVIET



CANITAL



EFFERGY

Appendix K 1

Subjects Details of Dyslexic Population

Experiment 1

Subjects	Ages	
	Chronological Age	Reading Age
Experiment 1		
C.H.	15;01	14;0
D.L.	14;5	10;7
A.D.	16;5	14;0
P.F.	16;4	12;7
J.B.	15;8	13;3
S.K.	15;6	12;9
M.H.	15;4	12;9
J.M.	15;6	10;7
L.M.	15;5	11;2
E.C.	14;2	11;9
P.S.	14;8	10;3

Appendix K 2

Subjects Details of Dyslexic Population

Experiment 2

Subjects	Ages	
	Chronological Age	Reading Age
Experiment 2		
M.B.	15;10	9;9
T.H.	14;10	10;9
P.M.	13;4	7;3
J.B.	13;8	9;9
G.A.	14;8	6;9
G.G.	14;9	8;9
M.R.	13;8	11;3
C.S.	14;3	10;3
G.H.	14;7	7;0
M.M	15;3	8;3
D.B.	14;4	12;3
P.S.	14;4	10;3
G.S.	15;2	12;3
T.R.	14;9	9;9
K.F.	16;0	13;3

Appendix K 3

Subjects Details of Dyslexic Population

Experiment 3

Subjects	**Ages**	
	Chronological Age	Reading Age
Experiment 3		
M.B.	15;10	9;9
T.H.	14;10	10;9
P.M.	13;4	7;3
J.B.	13;8	9;9
G.A.	14;8	6;9
G.G.	14;9	8;9
M.R.	13;8	11;3
C.S.	14;3	10;3
M.M.	14;7	7;0
D.B.	15;3	8;3
P.S.	14;4	12;3
G.S.	14;4	10;3
G.H.	15;2	12;3
T.R.	14;9	9;9
K.F.	16;0	13;3

Appendix K 4

Subjects Details of Dyslexic Population

Experiment 5

	Ages	
Subjects	Chronological Age	Reading Age
Experiment 5		
K.S.	13;4	8;3
T.H.	15;5	12;3
S.A.	13;01	6;6
P.M.	13;11	7;3
A.G.	15;2	6;3
A.M.	15;4	6;3
G.B.	14;0	9;2
J.B.	14;2	9;2
G.A.	15;3	7;3
G.G.	15;3	8;8
M.R.	14;01	10;8
C.S.	14;8	10;3
G.H.	15;01	7;3
M.M.	15;9	9;2
D.B.	15;9	12;9

Appendix K 5

Subjects Details of Dyslexic Population

Experiment 6

Subjects	Ages	
	Chronological Age	Reading Age
Experiment 6		
S.S.	14;1	7;3
K.S.	13;5	9;3
T.H.	15;11	10;3
S.A.	13;2	7;3
P.M.	14;4	7;3
J.J.	15;10	9;3
A.G.	15;4	7;3
A.M.	15;6	6;6
G.L.	14;5	7;6
G.B.	14;9	9;3
J.B.	14;8	9;9
G.A	15;9	7;0
G.G.	15;10	8;9
M.R.	14;8	12;3
C.S.	15;3	10;3