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Can the Baddeley and Hitch model of working memory account for learning to spell using multisensory spelling strategies?

by

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LIST OF SYMBOLS, ABBREVIATIONS AND NOMENCLATURE

Abbreviation	**Definition**
ADHD	Attention deficit hyperactivity disorder
AWMA	Automated working memory assessment
ES	Effect size
Estyn	Her Majesty's Inspectorate for Education and Training in Wales
DENI	Department of Education for Northern Ireland
DCSF	Department for Children, Schools and Families
DfES	Department for Education and Skills
HMIE	Her Majesty's Inspectorate of Education
LD	Learning difficulties
Ofsted	Office for Standards in Education
RAN	Rapid automatic naming
SACAWAC	Look, Say, Cover, Write, Check
SAS	Supervisory attentional system
SEED	Scottish Executive Education Department
SOS	Simultaneous oral spelling
SpLD	Specific learning difficulties
STM	Short-term memory
WM	Working memory
WMTB-C	Working Memory Test Battery for Children

ABSTRACT

This study had two aims. The first was to examine the relationship between working memory and spelling. The second was to explore how multisensory spelling strategies might support learning to spell within the framework of the working memory model of Baddeley and colleagues (Baddeley, 1986, 2000; Baddeley and Hitch, 1974). The sample comprised 124 children (mean age 9 years 4 months). In study 1, children's verbal short-term memory, visuospatial memory, verbal working memory, and spelling were assessed. Regression analyses showed that only verbal short-term memory was a significant predictor of children's spelling scores. In study 2, the children learned to spell words using three different study strategies: their normal spelling strategy; a *Look, Say, Cover, Write Check* strategy; and a *simultaneous oral spelling* strategy. Results showed that the children spelled significantly more words at post-intervention compared with pre-intervention but that no one spelling strategy was significantly more effective than another. Regression analyses exploring relationships between children's working memory scores and new words learned suggested that different multisensory strategies may draw upon different working memory components. Implications for practice are considered as well as suggestions for further research.

INTRODUCTION TO THE STUDY

This study is concerned with working memory and spelling. This study has two main aims. The first is to investigate the relationship between working memory and spelling. The second is to explore how multisensory spelling strategies might support spelling from a working memory perspective, specifically, how adequately the Baddeley and Hitch multi-component model can account for performance in learning to spell using such strategies.

The multi-component model of working memory first developed by Baddeley and Hitch in 1974 and later elaborated by Baddeley and his colleagues (see Baddeley, 1986, 2000; Baddeley and Hitch, 1974, 1994; Baddeley and Logie, 1999) is one of the most well-known and influential models of working memory. This model has sparked off an explosion of research and theoretical debate, leading not only to empirical confirmation of many aspects of the model but also to major developments of the original model. The model has been used widely as a basis to explore the relationship between different components of the working memory system (e.g. Gathercole, Pickering, Ambridge, and Wearing, 2004), as well as the development of academic skills such as reading and reading comprehension (e.g. de Jong, 1998; Gathercole, Alloway, Willis and Adams, 2006; Swanson and Jerman, 2007). However, very few studies have explored similar issues in relation to spelling.

Multisensory learning approaches are now well-established recommended remedial strategies for children with learning difficulties, particularly children with reading and spelling difficulties (e.g. Moats and Farrell, 2005; Snowling and Stackhouse, 2006). Multisensory strategies are those which combine the use of two or more senses simultaneously during the learning process, such as a visual strategy used simultaneously with an auditory and/or a kinaesthetic strategy (e.g. Snowling, 2000). However, despite their widespread acceptance within educational fields there are still only a few empirical studies available to support their effectiveness. In addition, no published studies have been located which have investigated how such strategies might support spelling from a working memory perspective.

This thesis will begin with a review of the literature from two main bodies of research, namely, spelling and working memory. A rationale for why spelling has been chosen as a focus for the study will first be outlined. The review will then go on to examine interventions for children with spelling difficulties, including those using multisensory approaches. Next, the main theories of spelling and what is currently known about the cognitive and working memory processes underlying spelling will be explored. Finally, theoretical perspectives on working memory will be discussed. The literature review will conclude with the proposal of a conceptual framework which locates the processes underpinning spelling within an architecture integrating theories of working memory and spelling development. The final chapters of this thesis will be concerned with the study method and findings together with implications for practice and suggestions for future research.

An outline of the main chapters is as follows. Chapter 1 will begin by presenting evidence of the prevalence and nature of the difficulties with spelling experienced by children in the UK (e.g. DCSF, 2009; Estyn, 2001; HMIE, 2006; Ofsted, 2004). The reasons why this should be a matter of concern will then be discussed, looking at evidence pointing to the importance of spelling for the development of other skills such as reading (e.g. Ehri, 1997; Frith, 1985) as well as for children's future life chances (e.g. Schramm and Dortch, 1991). The main section of this chapter will consider interventions for children with spelling difficulties. This section will begin with an overview of how our understanding of spelling development has evolved. This will then be followed by a systematic review of instructional techniques and word study strategies designed to help children learn the spellings of words more effectively. Studies examining multi-sensory techniques will be discussed in more detail as these are central to this investigation. The chapter will conclude with a summary of the main findings from the research.

Chapter 2 will review our current theoretical understanding of spelling. It will begin with an overview of the major spelling theories derived from developmental (Gentry, 1982; Henderson, 1990), cognitive (e.g. Barry and Seymour, 1988; Frith, 1985), and computational approaches (e.g. Brown and Loosemore, 1994; Houghton and Zorzi, 2003). The main focus of the chapter, however, will be on the cognitive factors thought to underlie spelling development. It will be argued that in contrast to what we know about the cognitive processes underlying reading, far less is known about similar processes in spelling particularly in relation to working memory. This chapter will also discuss how recent research into spelling has added to what is already known to suggest that the patterns of relationships between the cognitive factors thought to underlie spelling and those that have been shown to be important for reading development may be somewhat different (e.g. Savage and Frederickson, 2006; Savage, Pillay and Melidona, 2008; Scarborough, 1998).

Chapter 3 will consider theoretical perspectives on working memory. The Baddeley and Hitch multicomponent working memory model will be examined in some detail as the model has been used in the present study to explore specific gaps in the literature in relation to working memory and spelling. However, other theories and perspectives on working memory will also be discussed. This will be followed by an overview of how working memory is operationalised and measured in the literature. The chapter will conclude with a brief review of the research showing how working memory is thought to develop in children.

Chapter 4 will bring together some of the key elements from previous chapters to produce a conceptual framework to help understand the role of working memory in spelling. The main theories from which this framework has been derived are dual-route models of spelling and the Baddeley and Hitch model of working memory. However, it also draws on other theories of memory and learning. The processes involved in both learning to spell a new word and retrieving a word from long-term memory will be explored within this framework to provide an understanding of some of the mechanisms by which working memory might operate to support spelling. The chapter will conclude with the research questions this study seeks to address.

Chapter 5 will present the research studies with an account of the method used and an analysis of the results.

Chapter 6 concludes with a discussion of the main research findings, followed by implications for practice and suggestions for future research.

CHAPTER 1. SPELLING INTERVENTIONS

1.1 THE IMPORTANCE OF SPELLING

Literacy is at the heart of UK Governments' drive to raise standards in schools and improve life chances for young people (e.g. DfES, 2005; SEED, 2006). However, in contrast to the attention that has been given to reading both on the part of policymakers and from within the academic research area, spelling has been a relatively neglected subject. This chapter will explore this issue. First, evidence will be presented to show that large numbers of pupils leave the primary stage of education without having acquired basic spelling skills. Next, the importance of spelling for pupils' academic development, for their future life chances, and for the UK economy as a whole will be discussed. Finally, it will be argued that given the evidence demonstrating the importance of spelling, the lack of attention that has been paid to spelling relative to other areas of the school curriculum is a matter of some concern.

1.1.1 Evidence of the Extent of Poor Spelling

Statistics over the last few years have consistently highlighted that with respect to children's attainments in basic literacy in the UK, writing remains the weakest aspect of pupils' work, with spelling being the most common shortcoming (e.g. Estyn, 2001). In Scotland, the fourth national report on standards and quality in Scottish schools stated that of the schools inspected during the period 1998-2001, 45% needed to raise attainments in writing compared with a figure of 26% for reading (HMIE, 2001). A later report covering 2002-2005 showed pupils doing slightly better in both reading and writing in the early stages, but noted that this was not sustained though to P7 (HMIE, 2006). Gender differences were also evident, with almost half of all boys failing to achieve expected levels in writing by P7. In England a similar picture emerges, with reports by Ofsted showing the proportion of pupils gaining expected levels in literacy still below targets, with levels of achievement in writing well below those in reading (e.g. Ofsted, 2004). Statistics for 2008 show that only 68% of pupils left primary school having achieved an acceptable standard in writing (DCSF, 2009).

The evidence also suggests that problems with spelling are not confined to the current generation of school children. A survey of UK undergraduate standards of English conducted by Lamb (1992a) found that poor English, especially spelling, punctuation and grammar, was widespread in students in all subjects and in all universities surveyed (Lamb 1992a, as cited in Winch and Wells, 1995). In a second survey of 650 undergraduates within a single university, Lamb (1992b) also found that British students were far more likely to make basic spelling errors than those students with English as a second language. In addition, Lamb reported that many British students complained about his corrections of their work, saying that spelling 'was not corrected at school' (Lamb, 1992b, p.16). Lamb makes the point that he did not include students who were dyslexic in his study.

1.1.2 Why we should be Concerned

It is clear from the evidence that many children have difficulties with spelling. The question which needs to be considered is how much does this really matter? Intuitively, the answer to this question might seem straightforward. However, as Brown (1990) suggests, the literature reveals that perceptions of the importance of spelling appear to be very contradictory. For example, Gerber and Hall (1987) writing 20 years ago commented that "...demonstrable ability to spell is still imbued by an admiring public with connotations of studiousness, literacy, and intelligence," whereas a poor speller was often viewed as unintelligent (p. 34). A more recent study revealed that college students' perceptions of their peers writing ability and even of their intelligence was negatively affected by large numbers of spelling errors in a piece of writing (Kreiner, Schnakenberg, Green, Costello, and McClin, 2002).

In contrast, Winch and Wells (1995) discuss an alternative view which is held which considers that spelling, along with grammar, punctuation and handwriting, is a secondary attribute for a writer compared with the ability to be self-expressive and creative. Proponents of this view argue that educators should be more concerned with encouraging children's self-expression and creativity rather than emphasising spelling accuracy. A second more common argument which is often put forward against the importance of focusing on spelling accuracy is that the use of spell checkers has now made the need for correct spelling less important (e.g. Moats, 2007).

There are of course counter arguments to both these points. On the first point, Best (1992) argues that in order to be creative an individual must first possess an in-depth knowledge of a particular field. In the case of creative writing, this presupposes the use of accurate spelling and punctuation (Best, cited in Winch and Well, 1995). With regard to the second argument, research has shown that in order to benefit from the use of a spellchecker the writer must be able to produce a close enough approximation of a target words for the spell-checker to suggest the correct word. This demands a certain degree of accuracy on the part of the writer. For example, the study by MacArthur, Graham, Haynes, and De La Paz (1996) showed that a spell checker suggested the correct spelling for only 55% of the identified errors from the misspellings of students with dyslexic-type difficulties. These results have been supported by later studies that have demonstrated that spell checkers are generally ineffective in producing target words for the spellings generated by students with learning disabilities (e.g. Montgomery, Karlan, and Coutinho, 2001).

These debates aside, there is in fact an evidence base to show that spelling is a critical skill for children both in terms of their development in other areas and their future life chances. Considering the first point, many writers see the development of spelling as inextricably linked to the development of reading (e.g. Ehri, 1997; Frith, 1985; Waters, Bruck and Seidenberg, 1985). A full model of how spelling and reading develop and interact over time has not yet been developed (Caravolas, Hulme, and Snowling, 2001). However, although views on the exact nature of the relationship between reading and spelling vary, studies have suggested that spelling helps to lay the foundations for the development of reading in the early stages, principally by promoting phoneme awareness and letter-sound knowledge (e.g. Caravolas et al., 2001; Cataldo and Ellis 1988; Conrad, 2009; Ellis and Cataldo, 1990; Frith, 1985). Spelling can also be important for a pupil's writing development. It has been argued that poor spelling can damage the self-confidence of pupils as writers leading them to limit the complexity of their writing for fear of making mistakes (Graham, 1999). In addition, frequently having to attend to the spelling of a word when writing can interfere with higher order processes in writing such as planning and content generation (Berninger and Graham, 1998). Finally, misspellings in written or printed text can affect how others view the quality of their work. For example, there is evidence to suggest that poor spelling in assessments can influence the perception of the marker resulting in a lower mark (Chase, 1986; Marshall and Powers, 1989).

Turning now to the impact of poor spelling on future life chances, there is a wealth of evidence to suggest that poor spelling affects job opportunities and also career prospects. Schramm and Dortch (1991) found that even two misspellings in a résumé substantially reduced the likelihood that a job seeker would be granted an interview. The is extremely concerning, given that recent research carried out for the BBC by the Recruitment and Employment Confederation found that 47% of all CVs contained grammatical and spelling errors (see BBC News 24, 2007a). Poor spelling can also affect the ability to carry out a job effectively once in employment or training. A recent report by the Basic Skills Agency on army recruits noted that up to half of the 12,000 new recruits each year to the Army had literacy levels which were at or below the levels expected of 11-year-olds. A separate survey published alongside the report stated that more than half of Army managers found that poor skills in basic literacy prevented soldiers from carrying out their day-to-day jobs (see BBC News 24, 2007c). At a wider business level, a recent survey found technical errors in over half of the written work (55%) produced by clerical and administrative staff of the companies surveyed, despite having computers with spelling and grammar checkers (Basic Skills Agency, 2003). This may have serious financial implications for businesses. A Royal Mail survey reported that spelling and grammar mistakes could be costing UK companies more than £700 million a year due to lost business (Royal Mail, 2005: see also The University of Nottingham survey, press release, 2006; BBC News 24, 2007b; Learndirect, 2007, for further reports on the financial cost to businesses of poor spelling and basic skills).

In the face of such evidence, it is surprising to find that there seems to be a certain degree of ambivalence towards spelling in the push towards higher literacy standards by Government and Education Authorities. Spelling seems to have featured very little, if at all, in the majority of the large scale interventions that have been implemented to help those struggling with literacy. In a review of intervention schemes introduced in the UK between 1994 and 1998, all of the thirty approaches examined focused on reading (Brooks, Flanagan, Henkhuzens, and Hutchison, 1998). In a later revision of this report, only two out of the 25 schemes finally chosen for consideration had spelling as their sole focus (Brooks, 2002). There is also a question about the extent to which spelling is assessed in national examinations. As discussed earlier, surveys and reports have highlighted the fact that many children and adults have difficulties with spelling. However, we do not know how many, nor do we have any information about the nature or severity of children's spelling problems as there are no national standards which specify what a child should be able to spell and at what age. Both these issues are beyond the remit of this study to explore further. However, they have been noted to illustrate the point.

In summary, evidence has been presented to show that large numbers of pupils leave school without adequate spelling skills. Evidence has also been presented which demonstrates the importance of spelling for pupils' academic development and future life chances, as well as for the UK economy as whole. It has been argued that in comparison with reading, spelling has received relatively little attention both within government and academic spheres and that this is a matter of concern. In conclusion, there is a need to find more effective ways to support children in learning to spell. However, just as importantly, there is also a need to raise the profile of spelling in general within schools. It is hoped that the research carried out in this study will contribute towards these goals.

1.2 REVIEW OF SPELLING INTERVENTIONS

1.2.1 How Spelling Instruction has Evolved

Writing almost thirty years ago, Venezky (1980) noted that the search for effective strategies to help children learn to spell in English had a long history stretching back hundreds of years. Unfortunately, today we still appear be unable to draw any definitive conclusions about which spelling approaches are the most effective in teaching children to learn to spell (see Schlagal, 2001, for discussion). Research also shows that teachers lack confidence in their knowledge as well as application of many aspects of spelling theory and instruction (Fresch, 2007; Johnston, 2001).

One possible source of the confusion which appears to surround spelling instruction today may arise from the changing nature of our understanding of the spelling process. Spelling is now no longer viewed simply as a form of rote memorisation or learning, which was the case up until the 1960s (Treiman and Bourassa, 2000). On the contrary, it is now recognised that it is a complex and multifaceted skill which draws on a range of different sources of linguistic knowledge such as knowledge of letters (e.g. Muter, Hulme, Snowling and Taylor, 1998), the orthographic and the morphological structure of words (e.g. Nunes and Bryant, 2009; Treiman, Cassar and Zukowski, 1994), spelling rules (Rittle-Johnson and Siegler, 1999) and word-specific knowledge (Ehri, 1997; Juel, Griffith and Gough, 1986). It is now recognised that all of these factors play a part in the development of children's spelling, and that the degree to which children may use each factor varies across time (e.g. Cassar and Treiman, 2004; Varnhagen, McCallum, and Burstow, 1997).

Research during 1960s and 1970s into the orthographic and morphological character of the English language has also provided evidence to show that English is a much more consistent and predictable language than was first thought, and that a major portion of the language conforms to spelling rules (e.g. Chomsky and Halle, 1968; Hanna, Hanna, Hodges and Rudorf, 1966; Kessler and Treiman, 2003; Venezky, 1967). There is now growing interest in research into children's knowledge of rules governing the grammatical structure of words, particularly knowledge of morphemes and the importance of this for the development of proficiency in spelling (Bosman and Van Orden, 1997; Nunes, Bryant and Olsson, 2003; Nunes, Bryant and Bindman, 2006; Tsesmeli and Seymour, 2006). Unfortunately, research across languages has shown that even skilled adult spellers and many teachers are often unaware that many of these rules exist (see Bosman and Van Orden, 1997; Hurry, Bryant, Nunes, and Pretzlik, 2005).

A second factor which may have added to the difficulties in identifying effective spelling instruction is that very few of the large-scale intervention studies or schemes which have been implemented to raise levels of literacy have independently assessed spelling. Where spelling has been included in such intervention studies it is usually in combination with reading or writing or both (Brooks, 2002).

Finally, many of the intervention studies to raise general literacy levels suffer from flawed research designs which makes it difficult to have confidence in their findings. This includes failure to use random allocation, not having an appropriate control group, the use of measurement instruments with poor psychometric reliability and validity, inadequate reporting of information such as sample size, age of participants and appropriate descriptive statistics, and lack of attention to issues such as fidelity of treatment (see Brooks, 2002; Brooks et al., 1998). During the last decade, this issue emerged as a major concern affecting all of the effectiveness literature not only that focusing on literacy (Swanson, Hoskyn, and Lee, 1999). Today, there is a much better understanding of the elements of experimental design that provide the best evidence of casual effects and there are a number of publications that provide guidance on best evidence criteria (e.g. Institute of Education Sciences, 2006). Despite this, much of the research carried out still fails to meet the criteria for best evidence. This may be particularly pertinent to intervention research carried out in the 'real world', such as in schools and colleges, where it can be difficult to have as much control over conditions as might be wished (Robson, 2002).

Fortunately, notwithstanding these issues some broad general principles of effective spelling instruction have emerged from the literature (Scott, 2000). In addition, empirical support exists for a range of instructional techniques and study strategies which can help children to remember the spellings of words.

Turning to the broad principles first, it now appears to be generally accepted that in order for children to develop spelling competence they need to be 'taught' how to spell by direct instruction, which includes instruction in specific spelling strategies to help remember the spellings of words (Graham, 1983; Peters, 1985; Westwood, 2008). It is also recognised that instructional programmes require to be delivered within a literacy rich environment to allow the children to apply and generalise spelling skills learned (e.g. Graham, 1983, 2000; O'Sullivan and Thomas, 2007; Schlagal, 2001; Scott, 2000). This position reflects a balance between the 'taught' versus 'caught' proponents of spelling instruction. For example, those taking a whole language or 'caught' position have argued that children can learn what they need to know through informal and incidental methods of learning (e.g. Bean and Bouffler, 1987; Edelsky, Altwerger, and Fiores, 1991; Smith, 1982). However, others have argued that the bulk of the research shows that whilst some spelling knowledge can be 'caught' by some students, this may not occur for all students and that most students, particularly those with learning difficulties, require direct instruction in spelling to become competent spellers (e.g. Graham, 2000; O'Sullivan and Thomas, 2007; Peters, 1985).

A further key principle is that spelling instruction should match the developmental level of the child (e.g. Moats, 1995; Morris, Nelson and Perney, 1986; Morris, Blanton, Blanton, Nowacek and Perney, 1995). For example, the study by Morris et al. (1995) provided evidence to show that spelling instructional level is a strong predictor of learning and retention in conventional spelling instruction.

The focus of this chapter will be on specific interventions designed to help children learn the spellings of words more effectively, and research studies that have investigated such intervention strategies will now be reviewed. However, it is important to re-emphasise that these strategies are considered to be only one part of a much wider approach to helping children become more effective spellers.

1.2.2 Overview of Current Synthesis of Studies

The interventions reviewed here have been divided into two categories: techniques of instructional delivery such as distributed practice, and word-study strategies ranging from spelling by analogy to the use of multisensory methods. However, it is recognised that these are fairly broad categories which could be further subdivided and are also not mutually exclusive. The interventions employing multisensory strategies will be discussed in greater detail than the others as they are more central to the research questions explored in this study.

Twenty-seven studies in total have been considered. Eleven used a single-case design and 16 employed a group design. The studies have also been presented in schematic form in Table 1 noting relevant features including factors that relate to the quality of the research design. Effect sizes have been calculated for treatment-comparison studies to provide a standardised measure which can be useful when comparing different types of interventions. Cohen's *d* was used as the index for effect sizes. This was calculated as the difference between the mean posttest score of the intervention group minus the mean posttest score of the comparison group divided by the pooled standard deviation (Cohen, 1988).

Studies targeting children of all abilities have been considered. A number of the studies reviewed here can also be found in previous reviews of spelling research (e.g. Fulk and Stormont-Spurgin, 1995; McNaughton, Hughes and Clark, 1994; Wanzek et al., 2006). However, this present synthesis of the research provides additional information and includes other research not previously covered in earlier reviews.

Search procedures

The studies were located using the databases ERIC and PsychINFO and the search engines Google Scholar and Advanced Scholar. Descriptive used included *spelling, instruction, strategies, techniques, multisensory, learning disabilities, dyslexia, learning difficulties* and *schoolchildren* used in various combinations. Additional studies were located by tracking citations from relevant articles and from articles' reference lists. Studies published in both peer reviewed journals and in books were considered.

British vs. US classifications

Much of the published research on spelling interventions comes from America and focuses on students with learning disabilities (LD). This is a US legal classification based primarily on an IQ-achievement discrepancy relating to an unexpected underachievement in a specific skill area such as reading, reading comprehension, spelling, or mathematics, using IQ as a measure of potential (but see Morrison and Siegel, 1991, for discussion). In Britain, no such system for classification exists and similar groups of children would generally be described as having specific learning difficulties or dyslexia (if the skill area is literacy). In the studies examined here, the terms learning disability, specific learning difficultly (SpLD) and dyslexia are used interchangeably, and tend to reflect where the study originated from.

1.2.3 Techniques of Instructional Delivery

The techniques examined here include self-correction (Horn, 1947; Grskovic and Belfiore, 1996; McNeish, Heron and Okyere, 1992; McGuffin, Martz and Heron, 1997; Morton, Heward and Alber, 1998; Alber and Walshe, 2004; Harward, Allred and Sudweeks, 1994), error imitation modelling (Kauffman, Hallahan, Haas, Brame and Boren,1978; Nulman and Gerber, 1984, Gerber, 1986) and reduced unit size (Bryant, Drabin and Gettinger, 1981) with distributed practice (Gettinger, Bryant and Fayne, 1982; Guza and McLaughlin, 1987).

Table 1. Summary of Intervention Studies with Effect Sizes[1]

Study	*Intervention/* Design	Procedures	Duration	Sample	Assignment Procedures / *Fidelity Check*	Outcome Measures	Findings	Comments
Alber & Walshe, 2004 (US)	*Error correction by self-correction* Single-subject alternating treatments	T1. 10 words dictated through audiotape. Students self-corrected after writing all ten words T2. 10 words dictated through audiotape. Students self-corrected after each word.	25-30 min sessions on four consecutive days	6 male students with specific difficulties, aged 10-11 yrs	Order of presentation of conditions was kept constant for each week but varied randomly from week to week *No details given.*	No. of words spelled correctly on weekly test and one week maintenance tests Social Validity measures[2]	T2 > T1 for all five out of six students and for all six students on maintenance tests Students were equally divided over which conditions they preferred.	Information regarding students' prior spelling performance would have strengthened educational significance of results.
Bradley, 1981, (UK) Pilot. Exp 1	*Multi-sensory strategies* Repeated measures treatment comparison.	***Three conditions*** T1. Visual-Auditory-Motor T2. Visual-Auditory T3. Untaught 12 words - three groups of four.	Four consecutive days. Each day four words learned by (1) followed by (2) for approx 10 min.	10 students 9F / 1M *M* age=9:8 yrs Mixed – but mainly SpLD reading and spelling.	Words systematically varied between conditions *None described but researcher carried out the training.*	Pre-test. Two post-tests- end of week and 4 weeks later on Mean number of words spelled correctly.	Post-test 1 1 > 2 > 3 $p < .01$ Post-test 2 1 > 2 & 3 $p < .01$ 2 > 3 $p < .05$	Carefully designed but small sample – short duration. Small number of words No control for words possibly known at start.

[1] Effect sizes were calculated using Cohen's *d* where appropriate details were provided.
[2] Questionnaires to gather students' and teachers' views of the training.

Study	*Intervention/* Design	Procedures	Duration	Sample	Assignment Procedures / *Fidelity Check*	Outcome Measures	Findings	Comments
Exp 2	*Multi-sensory strategies* Repeated measures treatment comparison	Four conditions T1. Visual-Auditory-Motor T2. Visual-Motor T2. Visual-Auditory T4. Untaught 16 words – four groups of 4 words.	Four consecutive days Each day four words learned by 1,2,3 varied systematically initially 30 min day.	9 students. M age =11yrs M/F not given Mixed–SpLD with associated difficulties	Words varied between conditions and order of presentation of conditions varied *None described but researchers did the training.*	Three post-tests End of week, two weeks, four weeks later	Post-test 1 1, 2 & 3 > 4 $p < .01$ Post-test 2 1 > 2, 3 & 4 $p < .01$ ES: not enough data provided to calculate	Experiment more controlled than pilot but still small sample and short duration Also possible treatment effects.
Brooks and Weeks, 1998 (UK)	*Teaching methods - visual/ phonics/tracing* Mixed design (within and between subjects treatment comparison)	Three different teaching methods, one each week: T1. Visual/ semantic T2. Phonics T3. Tracing 10 words each day. Errors taught.	3 weeks	3 groups of children **Group 1=** dyslexic *M* age 14.3 **Group 2 =** Slow learners *M* age 14.3 **Group 3 =** spelling age-matched controls *M* age = 9.9	None described	No. of new words learned each week	Group 1 T2 > T1 Group 2 T1 > T2 Group 3 T1 = T2 = T3.	Number of weaknesses in methodological design However, one of the few studies to link the impact of various teaching/ spelling methods to pupils' cognitive profiles Issues would benefit from further research.

Study	*Intervention/* Design	Procedures	Duration	Sample	Assignment Procedures / *Fidelity Check*	Outcome Measures	Findings	Comments
Bryant et al. 1981 (US)	*Distributed practice* Between subjects treatment comparison	T1. 3 words day T2. 4 words a day T3. 5 words a day Daily instruction including oral /written spelling practice, immediate corrective feedback.	3 days 30-40 min daily	64 LD (43M/ 21F). *M* age = 10.2yrs *SD* = 14.2 Groups of 3 to 6	Random assignment to groups but class groupings kept where possible Groups randomly assigned to treatments *Training/ lesson scripts/ observations described.*	Ave. number and % of - nine common words, - additional words, - total words spelled correctly on posttest	Zero baseline scores on pretest No sig. difference in total number of words learned in each group (7 to 8 words). But % words correct on posttest: T1 = 83% T2 = 58% T3 = 57%	Treatment time kept more or less constant for all groups, so could have affected % mean words mastered Study of very short duration.
Cunningham & Stanovitch, 1990 (US) Exp 1	*Multi-sensory strategies and computer* Within-subjects repeated measures treatment comparison	Six conditions: Children individually trained T1a. Computer T1b. Computer with letter naming T2a. Letter tiles T2b. Letter tiles with letter naming T3a. Writing T3b. Writing with letter naming Total of 30 words Each child	4 days 30 min day approx	24 children M age=6:10 10M /14F Typically developing children	Words into two groups of 15 for naming/ no-naming Order fixed for motoric conditions but counterbalanced across children Order of naming factors counterbalanced across Mon/Wed	End of week test in writing words No. of words spelled correctly	T3 > T1 & T2 $p < .05$ T3 > T1 Ave ES = 1.00 T3 > T2 Ave ES = 1.00 No sig diff between T1 and T2 No sig effect for letter naming	Large number of conditions (6) with small sample Short duration No maintenance tests Effect of closer match between training/ test conditions for writing? 2nd experiment controlled for this and found

Study	*Intervention/* Design	Procedures	Duration	Sample	Assignment Procedures / *Fidelity Check*	Outcome Measures	Findings	Comments
		learned different words under the 6 different conditions.			and Tue/Thu *None described.*			handwriting still superior.
Darch et al., 2000 (US) Exp. 2	*Spelling packages* Between subjects treatment comparison	T1. Rule-based inst ruction; phonemic and morphemic analysis (Spelling Mastery) T2. Word families, and practice in sp. through writing (Laidlaw Spelling) .	3 weeks 12 instruction sessions of 20 min 4 per week	30 LD students Elementary stage	Students randomly assigned to treatment groups *Teachers randomly assigned. Training provided with demonstration and role-play. Lessons semi-scripted.*	% correct on 30-item spelling test	T1 > T2 (ES =1.76) $p < .01$	Age of students not reported Posttest only design so no control for difference between treatment groups, e.g. words known.
Englert et al., 1985 (US)	*Analogy training* Between subjects treatment comparison	Each student taught individually T1. 11 students taught analogy then practiced spelling out loud /writing from memory / cloze sentences. T2. 11 students. Practice in spelling the word out loud, writing from memory / cloze sentences.	4 weeks 3 x weekly 10 min sessions	22 students with mixed learning difficulties (i.e. specific and general) matched for grade reading age level	Matched pairs randomly assigned to either group *Yes – details provided* *Attempts to control for teacher effects.*	% of words spelled correctly on pre-test and posttests	T1 > T2 on target words, $p < .01$ (ES = 1.1) and on transfer words, $p < .05$ (ES = 1.35).	No data given on age of students but expect variable Variation in spelling ages and words learned – controlled for in an ANCOVA using pretest %scores Reading was also a component of this study.

Study	*Intervention/* Design	Procedures	Duration	Sample	Assignment Procedures / *Fidelity Check*	Outcome Measures	Findings	Comments
Fulk, 1996 (US)	*Multi-sensory strategies* Between subjects treatment comparison	T1. 5 step strategy T2. As above + attribution component T3. Choice from 4 different methods 36 words grouped into 10, 13, 13 for each day	3 days for training 3 sessions of 25 min	34 LD students Grades 7, 8. *M* age14.4 yrs (*SD* = 0.63) No. in groups 10-13	Random assignment to groups *Teacher scripts prepared but no description of fidelity checks.*	Means and % words spelled correctly on daily tests Generalisation tests – 13 words	**Daily tests** T1 > T3 (ES =1.25) $p < .05$ T2 > T3 (ES =0.76) No sig diff between T1 and T2 **Generalisation** T1 > T3 (ES=0.45), $p < .05$ T2 > T3 (ES=0.38) $p < .05$ No sig diff between T1 and T2 More T1 and T2 students employed strategy in generalisation than in control.	Well reported Small sample Limited duration -3 days Large number of words to learn each day but daily tests No details of how words already known controlled for Study explored strategy transfer but exploration of words maintained would also have been helpful.
Gerber, 1986 (US)	*Error-correction by imitation/ modeling* Single-subject posttest design.	3 lists of words 10 words Words corrected using imitation of		11 pupils with LD Aged 7-15 yrs	Not described.	Analysis of errors using SQR (spelling quality ratings) and CLS (correct letter sequences).	More correct spellings on first trial of each new list; fewer trials needed to reach criterion;	Limited information given regarding study design Concentration was on analysis

Study	*Intervention/* Design	Procedures	Duration	Sample	Assignment Procedures / *Fidelity Check*	Outcome Measures	Findings	Comments
		student error plus modeling Training for generalisation.					systematic improvement in spelling quality.	of errors.
Gettinger, 1993 (US)	*Error-correction by self-correction* Between subjects treatment comparison	T1. Regular spelling practice (15 word lists) T2. Regular spelling – reduced list (3 x 5 sets) T3. Error-correction procedure with students working in pairs 5 words lists Repeated practice to mastery.	3 x six week phases 1. Baseline 2. Intervention 3.Generalisation	Three matched 3rd-grade classes 65 students 31M /34F *M* age 8yrs 2 mo	Random assignment of conditions to classes *All papers double-scored* *Papers checked for use of appropriate procedures observations.*	Average correct on weekly tests Generalisation measures Average no. target words correct in dictated story Teacher ratings.	T3 > T1 and T2 (ES= 0.85) $p = .05$ T3 >T1 and T2 (ES= 0.56) $p = .05$ T3 >T1 and T2 (ES= 0.72) $p = .05$. Higher ratings on gen performance for T3.	T3 condition - children working in pairs Possible influence of cooperative learning
Gettinger et al., 1982 (US)	*Mixed treatment – distributed practice, error correction* Between subjects treatment comparison	T1. 17 training words presented in groups of three Instruction – mixed e.g. limited list, immediate corrective feedback, mastery practice, training for	3 weeks 8 sessions of 30 min. per day	39 with LD T I group = 24 *M* = 8.8yrs *SD* =12 T2 group = 15 *M* = 8.6yrs	Students randomly assigned to groups but T1 group assigned prior to T2 group, so not truly random assignment	No. of training words (out of 17) spelled correctly, no. of transfer words (out of 12) spelled on pretest and posttest.	T1 > T2 on both target words (ES = 0.82) and on transfer words (ES = 0.96).	T2 group studied 24 transfer words as well as the training words so less study time per word than T1 condition.

Study	*Intervention/* Design	Procedures	Duration	Sample	Assignment Procedures / *Fidelity Check*	Outcome Measures	Findings	Comments
		transfer 24 words tested for transfer T2. Traditional instruction All words used as training words.		*SD* = 7 Training in groups 2-5.	*Yes- details given* *Also 6 teachers for T1 groups and 3 teachers for T2 groups, randomly assigned.*			
Graham & Freeman, 1986 (US)	*Multi-sensory strategies* Between subjects treatment comparison	5-step strategy Students in T1, T2 and T3 received strategy training Study conditions: T1. Teacher Directed T2. Teacher-monitored T3. Student directed T4. Free study Two dictated word lists of 15 words each	30 minutes study Two study session sseparated by two days	40 students with LD 32M / 8F Mean age = 10 yrs 8 mo	30 test items randomly assigned to lists and position Order effects controlled Students randomly assigned to groups *Examiners recorded on-task behaviour during study conditions*	Subjects' scores on dictated words tests	*M* performance in each group T1, T2 and T3 >T4 $p > .01$ NS diff between T1, T2, T3. (Ave. ES = 1.1)	Carefully designed study However, no details of how words already known controlled for No examination of delayed recall or generalisability
Grskovic & Belfiore, 1996 (US)	*Error-correction by self-correction* Single-subject alternating treatments	T1. Traditional. Words were copied three times T2. Words dictated with immediate error correction and additional practice	30 min sessions for four days each week for 3 weeks	5 students of average ability with emotional difficulties (3M /2F) 4-5th grade (primary)	Words randomly assigned Half the words taught by one method and half by another in week Presentation of	No. of words written correctly on first day test and next day tests % of correct letter sequences	T2 > T1 for all students Students preferred the error correction to traditional method	Different sets of words chosen depending on students' spelling levels Baseline measures taken

Study	*Intervention/* Design	Procedures	Duration	Sample	Assignment Procedures / *Fidelity Check*	Outcome Measures	Findings	Comments
		Students compared with word written by instructor - only incorrect letters erased and corrected			order of conditions counter -balanced across sessions *Training carried out by first author* *Lessons observed using checklist by independent observer.*	Social Validity measures		(first day tests) were not always equal changing the number of possible words to be learned in each set Possible ceiling effect for some students Confounding effects cannot be separated out, e.g. use a dry-wipe board
Guza & McLaughlin, 1987 (US)	*Distributed practice* Single-subject alternating treatments	T1. Words presented at start of week by pre-test with error correction T2. Four lists of 5 words, tested following day with error correction Exercises during week similar – write word 5 times, write sentence, worksheets	$T1_1$ = 5 weeks $T2_1$ = 5 weeks $T1_2$ = 5 weeks $T2_2$= 5 weeks	13 normally achieving 4th and 5th grade 9M / 5F	None described *None described*	% of words spelled – end of week test	T2 > T1 $T1_1$ vs. $T2_1$ (t=5,n=13, p=.01) $T1_2$ vs. $T2_2$ (t=4,n=13, p<.01)	Selection of students' results analysed Good spellers scored well on both programmes Greatest effect for weakest spellers

Study	*Intervention/* Design	Procedures	Duration	Sample	Assignment Procedures / *Fidelity Check*	Outcome Measures	Findings	Comments
Harward et al., 1994 (US)	*Self-correction methods* Between subjects factorial treatment comparison	All spelling words dictated T1. SC after whole list – visual comparison T2 . SC after each word –oral comparison T3. SC after whole list –oral comparison T4. SC after each word –visual comparison Four lists of 25 words 100 words in total Mixture of words at three levels – advanced, normal, easy.	Four weeks Test and self-correction on Monday and Wednesday only End of week tests on Friday No other learning took place	209 4th grade pupils from two mainstream schools No mean age given	School groups stratified by gender and randomly assigned to treatment groups Instructors taught all four methods following randomized rotation schedule *Training for teachers given and lesson plans* *Random observations made*	Mean number of words spelled correctly on pre-tests, post-tests, and delayed tests Gain scores between pre and post-tests and pre-and delayed tests	Sig difference between groups using wordwise and listwise, i.e. T2 and T4 > T1 and T3. $p = 05$ Wordwise methods more effective on delayed tests also but NS, $p = .20$ No effect of type of presentation, or pre-treatment test scores Girls > boys on all tests.	No control group so no between-group effect sizes can be calculated No claim can be made regarding the relative effectiveness of this technique compared to normal practice Gain scores used which are more susceptible to measurement error.
Hulme & Bradley, 1984 (UK)	*Multi-sensory strategies* Within-subjects repeated measures	Replication of Bradley (1981) T1. SOS T2. VM T3. VA T4. Untaught	Four consecutive days training Each day four words learned by 1, 2,and 3 varied systematically.	Two groups of 9 Group 1 Average readers M age=6:9 Group 2 Poor readers M age=11yrs.	Words randomly assigned to groups Order of teaching conditions varied *None described*	Three post-tests End of week, two weeks, four weeks later	Post-test 1 Group 1: T1, T2 & T3 > T4, $p < .05$ 2 >1> 3(NS) Group 2: T1, T2 & T3> T4, $p < .05$ 1 > 2, 3, $p < .05$	Groups matched for reading and spelling age However, chronological age may be a confounding factor in relation to working

Study	*Intervention/* Design	Procedures	Duration	Sample	Assignment Procedures / *Fidelity Check*	Outcome Measures	Findings	Comments
		16 words – four groups of four.	Initially 30 min. sessions.				Post-test 3 Group 1 T1, T2 > T4, $p <$ .05 2 >1 & 3 (NS) Group 2: T1 > T2, T3 & T4, $p < .05$ 1>3 > 2 (S / NS).	memory and phonological vs. visual strategies Not enough data provided to calculate ES.
Kauffman et al., 1978 (US)	*Error correction by imitation/ modeling* Single-subject alternating treatments	Experiment 1 10 irregular words each week T1. Model only with daily instruction and testing T2. Imitation modeling with daily instruction and testing Experiment 2 20 words each week As above but words introduced gradually (new + review)	Exp 1 6 weeks Exp 2 4 weeks	Exp 1 2 eight- yr-old students with general learning difficulties Exp 2 12 yr-old boy with general learning difficulties	Treatments alternated weekly No details of any randomisation, e.g. of words Exp 2. Words randomly assigned *Tests double scored No other details provided*	Exp 1 Ave % of correct spellings following both procedures Exp 2 As above but also post-test after 1 week	Exp 1 T2 > T1 Exp 2 T2 > T1 Greater effect for irregular words on both immediate and post-test	Exp 1 Only irregular words Findings suggest condition more effective for irregular words but comparison data for Exp 2 only Exp 2 had only one student Would have been more robust had two been used to compare
Kearney & Drabman, 1993 (US)	*Mixed – error correction, training to mastery, look-write- say*	10 word lists 3 groups with different start points T1.Baseline	3 – 9 weeks. Approx. 30 min. sessions	7 students with LD Students in three different classes –these	No indication of how groups were selected for starting points	% no. of words spelled correctly on end of week tests	Significant differences between baseline scores and intervention	Multi-component intervention which included specific strategy training,

Study	*Intervention/* Design	Procedures	Duration	Sample	Assignment Procedures / *Fidelity Check*	Outcome Measures	Findings	Comments
	correction Multiple baseline alternating treatments	T2. Traditional methods T3. Intervention Mon: Own study of word list Tue: Test/correct errors by Write -Say letter-by-letter 5 times Wed: As above but errors corrected 10 times Thu: Errors corrected 15 times Fri: Test.		formed the three groups 4M age range 10.67 – 13.58 yrs 3F age range 10.50 – 11.83 yrs	*Tests double scored* *Procedures overseen by supervising teacher - no systematic observation/ checklist etc. described.*		scores $t(6) = 2.13, p < .05$	distributed practice and immediate verbal feedback by teacher therefore difficult to say which elements were more critical
McGuffin et al., 1997 (US)	*Error-correction by self-correction* Single-subject alternating treatments	T1. Traditional -Copy word five times T2. -Listening to recorded word list while looking at word -Writing each word from dictation -Self-correcting word if incorrect -Repeating procedure.	12 weeks Until procedure had been completed or until 20 min elapsed.	6 students (2M /4F) Poor spelling and at risk of academic failure.	Random allocation of procedures by flipping coin with no more than three continuous weeks with same procedure *No details provided.*	No. of words spelled correctly on weekly post-test 6, 8 and 10 weeks maintenance tests using T1 words at 6 weeks, T2 words at 8 weeks, and both T1 and T2 words at 10 weeks Social Validity measures.	T2 > T1 for all five students on weekly post-test, and for five out of six on maintenance probes Students preferred self-correcting method	Not clear how long procedures took Results for maintenance amalgamated into percentage across weeks, but a calculation at 10 weeks from figures suggests no difference between methods

Study	*Intervention/* Design	Procedures	Duration	Sample	Assignment Procedures / *Fidelity Check*	Outcome Measures	Findings	Comments
McNeish et al., 1992 (US)	*Error-correction by self-correction* Single-subject alternating treatments	20 words presented start of each week T1. Traditional - mixture of writing, arranging in alphabetic order, segmentation, dictionary T2.Daily self-correction using proofreading marks Total of 200 words learned.	10 weeks of 20 min sessions daily Four consecutive days using same procedure	5 students with specific LD (2M/ 3F) 13-14 yrs	No description given but results suggest conditions were varied across 10 weeks *Not clear*	No. of words spelled correctly on weekly test, 2 to 3 week maintenance test on words learned, and generalisation measures Social Validity measures.	T1 > T2 on weekly tests for all five, four out of five on maintenance tests, three out of five on generalisation to other settings	No details given on how words were chosen, or assigned to conditions Absences amongst students for part of the time. Generalisation measures – very low number of words found.
Morton et al., 1998. (US)	*Error-correction by self-correction* Single-subject alternating treatments	T1. 10 words dictated through audiotape Students self-corrected after writing all ten words T2. 10 words dictated through audiotape Students self-corrected after each word.	5 weeks No details given of duration of session	5 students with specific LD (3M /2F) aged 11-12 yrs	Both procedures used each day Order of presentation varied randomly each day *Observations using procedural checklists*	No. of words spelled correctly on weekly test and one week maintenance tests Social Validity measures	T2 > T1 for all five students and for four out of five on maintenance tests Four students out of five preferred the self-correction after each word	Information regarding students' prior spelling performance would have strengthened educational significance of results

Study	*Intervention/* Design	Procedures	Duration	Sample	Assignment Procedures / *Fidelity Check*	Outcome Measures	Findings	Comments
Murphy et al., 1990 (US)	*Multi-sensory strategies* Single-subject alternating treatments	T1. Baseline Traditional – Words presented start of week Practice in writing words in sentences, computer assisted spelling, private study T2. CCC. Look, say; copy; cover, write; check Repeat till correct	$T1_1$ = 7 weeks $T2_1$ = 9 weeks $T1_2$ = 6 weeks $T2_2$ = 14 week 20 min sessions 14, 16, 18 words per week No info on how many words each day	9 students with LD; 4F / 5M Age 8.8 – 12.3yrs *M* = 10 yrs	Treatments alternated weekly No details of any randomisation *Spelling sessions observed* *All tests double scored*	% correct words on weekly tests. Social validity measures	CCC scores higher than both baseline scores on weekly spelling tests Students preferred the CCC method to the traditional method	Duration of each treatment different Very variable scores amongst students No control for words already known described Treatment included a range of measures: strategy training; immediate self-correction, distributed practice
Nies et al., 2006 (US)	*Multi-sensory strategies* Single-subject alternating treatments	Two strategies T1. Look, say, cover, write, check (CCC). T2. Say, repeat, print (copy only) This was part of normal classroom procedures Three lists of 12 words per week. Each list- 6 words for each condition.	3 weeks 20 min each day per week	Two 3rd grade students, (1M / 1F) with LD	Random assignment of words to each condition Presentation order of conditions counter-balanced *Task analysis checklist used*	Daily spelling tests of words learned the day before – total no. of words correct Also retention measured by test on Mon of previous week's words Questionnaire for students.	Both pupils did better with CCC method on daily and weekly tests Mean retention (weekly) scores: CCC – 95% CO – 64% Students preferred the CCC method.	History – treatment interaction effects possible Only minimal details reported.

Study	*Intervention/* Design	Procedures	Duration	Sample	Assignment Procedures / *Fidelity Check*	Outcome Measures	Findings	Comments
Nulman & Gerber, 1984 (US)	*Error-correction by imitation/ modeling* Single-subject posttest design	Pre-test of 10 words Words corrected using imitation plus modeling Student copied correct spelling Second list of 10 unknown words tested for transfer,	10 learning trials spread over 10 days lasting 10-15 min Study conducted after school at home and w/e,	Pupil with LD aged 8.5 yrs	Words randomly administered during the learning trials *None described*	Analysis of errors using SQR (spelling quality ratings) and CLS (correct letter sequences)	Spelling on phonetically regular words improved compared with prior performance on spelling test Improved quality of spelling on test for transfer,	No information on what learning experiences were taking place (in school) during the intervention Researchers note student found the procedures to be aversive and/or punitive.
Thomson, 1988 (UK)	*Multi-sensory strategies* Repeated measures treatment comparison	Three conditions 1. No teaching 2. Visual inspection (VI). (Look, cover, say letters out loud, check.) 3. SOS No. of words unspecified	Not specified	20 dyslexic children. *M* age = 11:3	Order of presentation of conditions 2 and 3 switched for half the children *None described*	Mean no. of word spelled correctly No other details given	3 > 1 & 2 $p < .01$	Few details given re. method, findings, analysis

Study	*Intervention/* Design	Procedures	Duration	Sample	Assignment Procedures / *Fidelity Check*	Outcome Measures	Findings	Comments
Thomson, 1991 (UK) Need to check details –sig levels?	*Multi-sensory strategies* Repeated measures treatment comparison	Two different groups of children took part. Children worked in pairs. 1. Visual inspection (VI). (Look, cover, say letters out loud, check.) 2. SOS 10 words used.	2 weeks Daily teaching sessions	Group 1 20 dyslexic children. *M* age: 9:10 Group 2 20 control children. *M* age: 7:6	Children in each group randomly allocated to either condition *None described*	Posttest on Monday following the two week training Mean number of words spelled correctly on posttest.	Group 1 2 > 1 *P*<.02 Group 2 2 = 1	Lack of details regarding method, results and analysis Children worked in pairs in this study – possible confounding effect.
Torgesen et al. 2001 (US)	*Comparison of two instructional programmes for Reading* Longitudinal treatment comparison	T1 = auditory discrimination in depth (ADD) T2 = embedded phonics (EP) 1-1 training	For each cohort: 8-9 weeks of two 50 min sessions daily Total 67.5 hrs. Also 8 weeks generalisation training	20 LD children each year for 3 years –50 in final total Ages 8-10	Random assignment to groups *Details provided of training/ weekly discussion /more than one teacher to each condition*	Standardised spelling tests: spelling and developmental spelling	Both groups showed improvements in spelling After one year sig diff favouring EP but effect lost at 2 years	Main emphasis on reading No control group Reasons given : 1. Baseline or pre-intervention data available (but only discussed re. reading) 2. High intensity of treatment intervention so control said to be meaningless

Study	*Intervention/* Design	Procedures	Duration	Sample	Assignment Procedures / *Fidelity Check*	Outcome Measures	Findings	Comments
Vaughn et al., 1993 (US)	*Mixed treatment comparing response modality (writing, tracing, computer).* Within subjects treatment comparison	T1. Writing T2. Tracing T3. Computer Instructional procedures: Individual word list; three words a session; compare and correct with modeling, reinforcement, error analysis and reinforcement. 30 words presented 10 per condition.	11 day programme 20 min sessions per day	48 children from Grades 3 and 4 Two groups Group 1 24 with LD Group 2 24 NLD	Words randomized across conditions Each motoric condition used in each session but conditions counter]balanced across each day *Research assistants trained in the procedures but no details of fidelity checks given.*	No. of words spelled correctly at posttests (2) and at one month follow-up. Interviews with students	No significant effect of motoric condition for either group Group 2 > Group 1 in no. of words learned and also retained at follow-up Students tended to prefer the computer but felt they had learned better with writing.	Individual word lists prepared for each student based on words they could not spell Both groups showed sig decline in words spelled correctly at follow-up but no sig diff in proportion of words retained.

Error Correction – Self-correction

Error correction has been shown to be a critically important factor in learning to spell words. There is a substantial body of evidence to show that a pre-test with immediate feedback and correction prior to study is more effective than the traditional 'study-test procedure' (i.e. list of words given to learn on Monday and tested on Friday). The first published study to report on this was conducted by Horn in 1947. As a result of his study, Horn concluded that the self-corrected test was 'the single most important factor contributing to achievement in spelling' (Horn, 1947, p. 258). Although this claim would not be made today, numerous studies since that time have supported the finding that the self-corrected test remains an efficient way to learn how to spell words (see Graham, 1983, for discussion).

The early study by Horn did not provide information about the method of self-correction used. However, since then studies have explored self-correction in detail examining not only different types of self-correction strategies but also factors which might contribute to the effectiveness of particular methods. All of the studies examined in this sub-section are single-case studies except that of Harward et al. (1994) which utilised a factorial between-group design.

The study by McNeish et al. (1992) compared a letter-by-letter self-correction method with proofreading marks (add, omit, reverse, wrong letter) with a traditional method of learning to spell. The participants were five learning disabled students aged around 14 years of age. The results indicated that for all five students the self-correction method was more effective in learning to spell the words than the traditional method, and that maintenance of words (two to three weeks later) was higher for four of the five students. Generalisation also occurred for three students, although the results suggest that the effect was minor. Interviews with students following the training indicated that the students preferred the self-correction to the traditional method. No details were reported on how words were chosen or assigned to conditions.

The self-correction method has also been examined whereby students corrected only incorrect letters (Grskovic and Belfiore, 1996) and where a whole-word procedure was used (McGuffin et al., 1997). In the study by Grskovic and Belfiore (1996), self-correction by erasing only incorrect letters using a dry-wipe board was compared with a procedure that required the students to write the correct word three times. Five pupils from Grades 4 and 5 (ages not given) described as having emotional and/or learning difficulties took part. All of the students learned more words in the error-correction condition. They also reported that they preferred this method. This study does not describe how it controlled for words already known and there was a possible ceiling effect for some students. Also, there may have been other effects that could have contributed to the results, such as the use of a dry-wipe board in the self-correction condition and comparisons with the instructor's performance. These were factors not present in the comparison condition. In the study by McGuffin et al. (1997) which ran for 12 weeks, a self-correction method was used whereby students wrote down a word from dictation and compared their version with the correct version. Six students with a mean age of 8.7 years took part. Errors were corrected by writing the whole word above the error. This method was compared with a 'traditional' method which required the students to copy the word five times. For all 6 students, the error correction procedure resulted in a greater number of words spelled correctly in weekly posttests and in maintenance tests (6, 8 and 10 weeks).

In the study by Harward et al. (1994) using a between-group design, 209 Grade 4 children (no mean age given) from two schools participated. Four different self-corrected test methods were compared. The factors investigated were (a) timing of feedback (word or list), and (b) mode of presentation of words (oral vs. visual). Pre-test scores were used as a covariate. Gender was also included as a factor. The children were stratified by gender into two subgroups and then randomly allocated to one of four treatment groups. The results showed a significant difference from pre-test to post-test favouring correction after every word (wordwise) as opposed to after a list of words. Students in the 'wordwise' groups still performed better on four-week maintenance tests although the results were not significant. There were no significant differences in terms of presentation mode (visual or auditory). Girls outscored boys on all tests. The results were similar across both schools and at all ability levels. Ability level appears to have been measured by performance on pre-test scores. This study used a large sample, with random assignment to treatment groups and treatment fidelity considered. However, no control group was used so no effect size can be calculated or claim made regarding the relative effectiveness of this technique compared to usual practice. The sample comprised a normal population of children but the possibility of any differential effect of the treatments depending on spelling ability was not explored. Gain scores were also used which are more affected by measurement error.

The timing of self-correction has also been explored by Morton et al. (1998) with five students with learning disabilities aged between 11 and 12 years of age. The results showed that the students spelled more words correctly on end-of-the-week tests and 1-week maintenance tests when they self-corrected after each word compared with when they self-corrected after attempting 10 words. This study was repeated by Alber and Walshe (2004) using a mixed group of students with learning disabilities and ADHD aged between 10 and 11 years of age. The results showed a high level of variability for test scores from week to week for all students. However, self-correcting after each word produced slightly more words spelled correctly on weekly tests for five of the six students, and slightly more words spelled correctly on maintenance tests for all six students.

In summary, the studies reviewed above have examined different types of self-correction procedures and compared these with different types of 'traditional' procedures such as copying out the correct word a number of times or using traditional methods of study during the week. Three of the studies also explored the timing of self-correction. The studies all employed different methodologies and therefore direct comparisons cannot be made. However, the evidence suggests that self- correction resulted in a greater number of words being learned as measured by end of week tests, and for some students there was evidence of short-term maintenance. There is no clear evidence of generalisation. The results suggest that this type of strategy may be effective for students at different ability levels, although this is not certain. Three of the studies suggest that the timing of self-correction is important, with immediate self-correction being more effective than self-correction after a list of words.

Error Correction - Imitation modelling

A number of studies have examined the effect of directing students' attention to their errors by imitation of the errors prior to the presentation of the correct model. The studies examined here used a range of designs.

An early study by Kauffman et al. (1978) compared the effect of teacher modelling (i.e. 'This is the correct way to spell that word') to imitation plus modelling, (i.e. 'This is how you spelled that word: here is the correct way to spell that word'). Two experiments found that imitation plus modelling resulted in faster acquisition rates and higher percentage of correct spellings for students with learning and behavioural difficulties. The authors suggested that comparing correct and incorrect spelling may help to focus students' attention on the difference between the error imitation and the correct spelling (Kauffman et al, 1978). The results suggest that the effect was only shown for irregular words. However, only two students took part in the first experiment and only one student in experiment 2.

A later series of investigations by Gerber and colleagues (e.g. Gerber, 1986; Nulman and Gerber, 1984) investigated qualitative as well as quantitative improvements in spelling performance using error imitation plus modelling. The researchers used a modification of error classification schemes developed by Gentry (1977) and Zutell (1978) (both cited in Gerber, 1986). Following the training, the students' performance suggested a gradual improvement in their understanding and application of orthographic rules rather than just rote memorisation of increasingly longer strings of letters. However, the design and lack of detail reported in these studies makes it difficult to examine their validity. The study by Nulman and Gerber (1984) investigated the imitation-modelling procedure with an eight-year-old boy whose baseline scores were said to average around 25% correct. The student's spelling on phonetically regular words improved and on a test for transfer, the quality of his errors also improved. However, the training took place at home after school and there was a possible effect of other learning experiences taking place in school. The study by Gerber (1986) employed similar general procedures with 11 students aged 7 to 15 years old except that training took place in school and three lists of similar words were used. The focus of these studies just described was on qualitative changes in spelling performance, with limited reporting of experimental details.

A study by Gettinger (1993) provided evidence of the generalisability of error correction and practice procedures to regular classroom instruction. Three matched classes of typically achieving third grade students, average age 8 years and 2 months, were randomly assigned to one of three groups: (a) regular spelling practice, (b) regular spelling practice with words broken down into smaller sets for study, and (c) a modified imitation modelling error correction procedure with repeated practice. The results showed significantly higher spelling accuracy scores both on weekly tests (ES= 0.85) and end-of-phase dictated story writing (ES = 0.72) for the error correction group compared with both other groups. A moderate effect size was also found on measures of generalisation (ES= 0.56). Teacher ratings of general spelling performance were also higher for the experimental group. The results of this study suggest that the error correction with repeated practice can be more effective in helping children to learn words than traditional practice incorporating workbook exercises, writing sentences and word study. However, there was an additional feature of the experimental group that was not controlled for which was that the children worked in pairs. Van Oudenhoven, van Berkum, and Berkum (1987) have documented that studying in pairs produced better spelling than studying individually. Therefore, it is not known to what extent some degree of cooperative learning contributed to the result.

Distributed practice and daily testing.

A number of studies have investigated the effectiveness of reduced word list size and distributed practice on spelling performance (Bryant et al., 1981; Gettinger et al., 1982; Guza and McLaughlin, 1987; Rieth et al., 1974).

Bryant at al. (1981) investigated the effect of varying the number of words to be learned each day with daily instruction which included oral and written practice in spelling and immediate corrective feedback. Sixty-four students with LD aged around 10 years of age ($M = 10.2$) were divided into three treatment groups that differed only in the number of phonemically irregular words taught (three, four and five per day) across three days of instruction. Students were randomly assigned to three groups (with some restrictions) and the groups randomly assigned to treatment conditions. Posttests showed no significant difference between the total numbers of words learned in each condition. However, the students who studied three words a day achieved a significantly higher percentage of words correct (83% correct) compared to scores of 58% for the 4-a-day and 57% for 5-a-day conditions. In effect, this study showed that regardless of the number of words presented, the students learned to spell correctly between seven and eight words within a three-day instructional period. The experimental teachers reported students displayed less fatigue and distractibility in the three word condition. The authors hypothesised that introducing more than three words a day may result in a processing overload for many students with LD leading to reduced learning as well as greater fatigue and loss of concentration. In this study, instructional time was kept relatively constant and therefore the time available to study each word was reduced in each condition. Not enough details were provided to calculate effect sizes.

The study by Gettinger et al. (1982) compared a multi-component intervention package that included limiting word length, distributed practice with immediate corrective feedback, mastery learning, and training for transfer, with a control group who were receiving traditional instruction. Thirty-nine students with LD and a mean age of 9 years took part. The results showed better performance on spelling post-test measures of both training words (ES = 0.82) and transfer words (ES = 0.96) for the experimental group. Students were randomly chosen from a pool of 50 matched students, although the experimental group was assigned prior to the control group. There was, however, a confounding factor: the control group also studied 24 transfer words as well as the training words which meant that the two groups were not comparable. That said, the results demonstrated the effectiveness of the experimental method over the control method, although it is not possible to draw any conclusions regarding the relative effectiveness of the various treatment elements.

A single-subject design study by Guza and McLaughlin (1987) compared the system of presenting all spelling words at the beginning and testing at the end of the week with a system of presenting a portion of the words each day and daily testing. Thirteen Grade 4 and 5 normally achieving students (mean age not given) took part. Results for six individual students chosen to represent three spelling ability groups, high, average, and low, were also examined in addition to group outcomes. The overall results showed there was a significant increase in spelling performance for almost all students in the daily testing condition. There was also a differential effect for students. The good spellers did well under both conditions, whilst the most substantial gains were found for the two weakest spellers. These results were consistent with earlier findings by Schoephoerster (1962) who compared variations of a standard 'pre-test on Monday, post-test on Friday' spelling routine with three ability groupings. While above average spellers did well regardless of condition, average spellers benefited for a midweek test and low-ability spellers benefited from daily practice as well (Schoephoerster, cited in Gettinger et al., 1982, p.440).

In summary, the above studies provide evidence that reducing the number of words to be learned and distributing practice of words over a longer period helps children with spelling difficulties to learn words more effectively. These techniques could also help average spellers, although good spellers appear to do well without such modifications to practice. However, it is difficult to know which of the variables – reduced word list size or distributed practice – is the most important.

1.2.4 Word-Study Strategies

Studies have shown that children with learning difficulties often fail to apply effective strategies when learning to spell (Darch, Kim, Johnson and James, 2000; Gerber and Hall, 1987) as well as for a range of other learning tasks (Torgesen, 1980).

Interventions in word-study strategies for which there is empirical support include analogy training (Englert, Hiebert and Stewart, 1985), rule-based approaches (Darch et al., 2000), instruction in phonemic decoding (e.g. Torgesen et al., 2001), *'Look, Cover, Write, Check'* procedures (Nies and Belfiore, 2006; Fulk, 1996; Kearney and Drabman, 1993; Graham and Freeman, 1985; Murphy, Hern, Williams and McLaughlin,1990) and simultaneous oral spelling methods (Bradley, 1981; Hulme and Bradley, 1984; Thomson, 1988; 1991).

Analogy strategy

In the study by Englert et al. (1985), 22 students with LD reading at Grade 2 level (mean age not reported) were randomly assigned to two groups. One group, the control group, received traditional spelling instruction for target and transfer words. The second group were instructed in an analogy strategy based on the rule that parts of words that rhyme are often spelled the same. The study showed that the students trained in the analogy strategy were better able to spell high-frequency sight words (ES = 1.4), as well as untrained transfer words (ES = 1.1), than the control group. The authors suggest that this study underscores the importance of students being taught geneneralisation strategies and being given the opportunity to practise the strategy in spelling new words. These factors have also been noted by other researchers as being very important for the development of efficient spelling abilities (e.g. Gerber, 1986).

Rule-based strategy

In the study by Darch et al. (2000), a rule-based strategy focusing on rules using phonemic and morphemic strategies was compared with traditional instruction (writing activities based on word families, practice in spelling words and motivational activities). Thirty students with LD at the elementary stage (mean age not reported) were randomly assigned to either group. The results showed that students learned words more effectively using the rule-based strategy (ES = 1.76). However, this study used a posttest design and which does not account for words already known before training.

Phonemic decoding

Few studies have specifically investigated the effect of phonics instruction on spelling *per se.* Where spelling has been assessed this has usually been as part of a general literacy programme with reading as the main focus. One such study is that by Torgesen at al. (2000). This study compared two instructional programmes, Embedded Phonics (EP) and Auditory Discrimination in Depth (ADD), both of which provided explicit and systematic instruction in word-level reading skills. However, one programme (EP) placed a heavier emphasis on direct phonics instruction.

This study ran for 3 years, with 20 children taking part each year. The instruction component ran for eight weeks followed by eight weeks generalisation training. The results showed that both programmes produced very large improvements in generalised reading skills that were stable over a 2-year follow-up period. In terms of the effects on spelling the results were inconclusive, and there is a lack of data or follow up discussion regarding spelling. However, the results suggest that both groups showed improvements in their standardised spelling scores following the intervention. The difference between the groups only became significant after a 1-year follow up period, favouring the EP group. The results also suggest that this effect was lost during the follow-up period of 2 years.

Look, Cover, Write, Check strategies.

'Look, Cover, Write, Check' strategies are probably amongst the earliest and most widely known spelling strategies (e.g. Horn, 1919, cited in Graham, 1983). Such strategies could be termed 'multi-sensory' in that they specifically engage two or more of the senses in the learning process, e.g. a visual, oral, or kinaesthetic element.

The study by Graham and Freeman (1985) trained students with learning disabilities to use a 5-step strategy based on Graham's (1983) recommendations, with an additional kinaesthetic element (trace the word). The students were required to (a) say the word, (b) write and say the word, (c) check the word, (d) trace and say the word, (e) write the word from memory and check, and then repeat the first five steps. Forty Grade 4 students with LD and a mean age on 10:8 years took part. Spelling performance was examined under different study conditions ranging from teacher directed to independent study. Results indicated that students who were taught the strategy learned more words than those who devised their own study methods. There was no difference under different study conditions (mean ES = 1.1). According to the authors this suggests that students with learning disabilities are capable of self-regulation of organised, strategic behaviour if given strategy training. The authors note that the results provide support for the contention that students with learning problems should not be allowed to devise their own methods for learning spelling words. This study did not examine delayed recall of words or generalisability

The study by Fulk (1996) investigated this 5-step strategy with explicit training for transfer and an additional attributional component. Attributions are explanations that individuals construct to explain outcomes, and it has been shown that students who are more likely to attribute success and failure to external causes are less likely to be motivated to apply effort in learning (Weiner, 1979).

Thirty-four LD adolescents with a mean age of 14.4 years were randomly assigned to one of three treatment groups: (1) strategy training, (2) strategy plus attribution training, and (3) traditional study. The traditional method was chosen by each student from a selection of (a) verbal rehearsal, (b) writing the words three times, (c) sentence practice, and (d) orthographic spelling puzzles, following practice in all four methods. Results indicated that significant differences occurred on spelling recall scores across the training days favouring the 5-step strategy training conditions (mean ES = 1.01). Effect sizes were smaller (mean ES = 0.45) though still within the moderate range for assessments designed to determine generalisation effects on untrained words. In this study, attribution training did not result in greater spelling performance, strategy transfer, or numbers of attributions to effort.

Look, Cover, Write Check strategies have also been investigated by a number of single-case studies and have been found to be more effective than traditional methods. However, some of these studies included additional components which makes their interpretation difficult. For example, the studies by Murphy et al. (1990) and Kearney and Drabman (1993) included a distributed practice element in the experimental condition. Murphy et al (1990) compared a 'look, say, copy, cover, write, check' procedure (CCC) with a traditional procedure where words were presented at the beginning of the week followed by sentence writing, computer practice and self-study. This study showed that the CCC method was more effective than a traditional method according to percentage scores on weekly spelling tests. The average mean score was 82.76% correct in the traditional condition rising to 93.0% in the CCC condition. The study was conducted over quite a long period of time (36 weeks).

In the study by Kearney and Drabman (1993) a multiple- baseline design was used across three groups of students with the intervention introduced at 2, 4 and 6-weeks following baseline assessments. In the experimental condition there was daily testing with the teacher giving verbal feedback. Errors were corrected by writing the word out an increasing number of times. It would appear that errors were corrected by the student saying the letter name out loud as the word was written but this is not clear. Significant differences were found between baseline scores (mean 58.8%) and intervention scores (mean 79.3%) with a final week write-say score of 88.6%.

A single-subject study by Nies and Belfiore (2006), using the same distribution of practice in both conditions, compared the effects of a look, say, cover, write, check strategy (CCC) with a copy-only procedure. Two students with learning disabilities took part. The results showed that both students learned and retained more words in the CCC condition compared to the copy-only condition. Both students also preferred the CCC method and felt they did better with this method. The authors attribute the main success of this intervention to the impact of the self-evaluation and self-correction component of the CCC condition. However, whilst these factors are undoubtedly important, the authors don't discuss another possible effect on learning in the CCC condition which was having to write the word from memory before checking. Studies have repeatedly demonstrated that learning is improved when learners are required to actively retrieve information from memory (e.g. Carrier and Pashler, 1992; Dempster, 1996).

Simultaneous Oral Spelling

The Simultaneous Oral Spelling (SOS) method is similar to *Look, Cover, Write, Check* methods but it includes an additional component which requires the student to say the alphabetic name of each letter out loud as it is written. The SOS method was at the core of the methods recommended by Orton (1937). Orton's approach to help children with literacy difficulties was designed to support both reading and spelling skills. However, he made a particular distinction between reading and spelling. Orton argued that spelling was a much harder skill to acquire than reading and that 'unless very careful attention by appropriate measures be given to spelling as well as to reading, the child may progress very little in the former' (p.85). Orton's methods incorporated an explicit phonetic component, emphasising the importance of sound dissection of words, in addition to a multi-sensory approach. This was because Orton felt that the spoken word was "acquired in both the auditory memory and in the speech mechanism as a unit and not as a blend of its parts and often the child is completely at sea at first as to how to approach the dissection" (p. 166). Orton felt that the SOS method made all the necessary linkages between vision, audition and kinaesthetic. The SOS method is widely recommended by both practitioners and policymakers (e.g. DENI, 1998; Dyslexia Scotland, 2005; DES, 2007). However, evidence for its effectiveness still comes from only a few studies (e.g. Bradley, 1981; Hulme and Bradley, 1984; Thomson, 1988; 1991).

Bradley (1981) used a repeated measures design to investigate the SOS method in two different experiments. In the preliminary experiment, three study conditions were compared. These were a) naming each letter while writing (SOS), (b) a no writing condition using letter tiles to form words (VA), and (c) a no-treatment condition (UT). Ten children with a mean age of 9 years 8 months with specific learning difficulties took part. Twelve words were divided into three groups of 4. The results of this pilot experiment showed that the children spelled significantly more words correctly at post-test in the SOS condition compared with the other conditions and this was maintained after four weeks. However, there was no control for words already known or for treatment effects.

The second experiment was carried out to try to ascertain how important writing was to the efficacy of the SOS method. Nine children with a mean age of 11 years with specific learning difficulties took part in this experiment. Following pretesting, 16 words which none of the children could spell were selected and divided into four groups. Four conditions were compared: three were the same as in experiment 1, that is, SOS, VA and UT. The fourth condition introduced was visual auditory motor (VAM). In this condition, the child wrote the word and said its name as it was written but did not name the individual letters (similar to the *Look, Say, Cover, Write, Check* methods). Each child learned four words in each of the training conditions on four consecutive days. The four groups of words were varied systematically between conditions and the order of presentation of conditions was varied between the children. Three post-tests were conducted: end-of -week, 2 weeks and 4 weeks later. The results showed that the three teaching conditions were superior to the untaught condition ($p<.01$ in each case). The greatest number of words were learned in the SOS condition although this difference was not significant.

However, by the end of the third post-test, only the SOS condition was superior to the untaught condition ($p < .01$) and it was also superior to each of the other conditions ($p < .01$ in each case). Bradley argued that the results of her study suggest that writing words alone is not sufficient when learning to spell words, at least for children with learning difficulties. She suggested that the SOS method helped children to understand that the word could be broken down into different phonemes and to establish a one-to-one relationship between the spoken and written symbol. She also suggested that the method helped to link the visual and auditory modalities through writing. At the time this study was conducted, the usefulness of effect sizes was not yet recognised and, unfortunately, insufficient details have been reported to allow these to be calculated.

The Bradley (1981) study was later replicated by Hulme and Bradley (1984) and the same results were found for the children with spelling difficulties, which was that the SOS method was significantly superior ($p < .05$) to the other three methods used. This study also compared the performance of this group with a group of children of average reading ability. For the group of average readers, a significant effect was found for the two writing conditions. However, naming did not enhance the effect. Again, no effect sizes can be calculated. The study by Cunningham and Stanovitch (1990) with Grade 1 children provided additional evidence that writing though not letter naming was a critical factor in learning to spell for children without reading difficulties. This study compared the effectiveness of training words using handwriting, letter tiles, or the computer keyboard. The results showed that children learned significantly more words in the handwriting activities but there was no significant effect for letter naming in any of the conditions. The average effect sizes for the differences between the writing conditions and both the tile and the computer conditions was 1.00 in each case. This study used a repeated measures design involving 24 children learning 30 words under six different conditions over four days. Although care was taken to counterbalance conditions, there may have been treatment effects. There was also no follow-up for maintenance.

Two studies by Thomson (1988, 1991) have also demonstrated support for the SOS method. In the 1988 study, the SOS method was compared with a no-treatment method and a method termed visual inspection (VI). This involved a visual element (look) and an auditory element (say the letters out loud). Twenty children with dyslexia and a mean age of 11 years and 3 months took part. The SOS method was found to be significantly superior to the other methods. However, few details about the study design and findings are reported. The Thomson (1991) study involved 20 children with dyslexia and a mean age of 9 years and 10 months. The performance of this group was also compared with a group of normally achieving children matched for reading and spelling age. The results suggest that for the dyslexic children the SOS method was more effective in helping them to spell words than the visual inspection method. For the children without spelling difficulties, both strategies were equally effective. However, this study also suffers from a lack of detail reported. The children also appeared to be working in pairs, which may have been a possible confounding factor.

The above experiments have demonstrated the efficacy of the SOS method, at least for children who have literacy difficulties. It is unfortunate that most of these studies report insufficient details for the calculation of effect sizes. Some of the results also have to be interpreted with caution given their limited generalisability (small sample sizes) and there is some ambiguity in the reporting in some studies. That said, the findings of the effectiveness of the SOS method for struggling readers and spellers are strengthened by the consistency with which they have been shown.

The evidence also suggests there is a differential effect for the SOS strategy between poor and normal readers and spellers, at least for the letter naming component. The studies by Hulme and Bradley (1984) and Cunningham and Stanovitch (1990) suggested that whilst writing was a critical component in learning to spell for average readers and spellers the effect was not enhanced by letter naming (see also Thompson (1991).

Hulme and Bradley(1984) suggest that the benefit of naming for children with learning difficulties relates to their problems in segmenting speech and coding print into verbal memory. For normal readers who do not have these difficulties, systematically naming each letter in a word seems to be an irrelevant activity which does not help them learn to spell the word (Hulme and Bradley, 1984, p441). However, alternative explanations are also possible, both relating to developmental stages. The Hulme and Bradley (1984) study and the Thomson (1991) study compared children of different ages (the children were matched for reading age which meant that the non-disabled readers were younger than the disabled readers). Thomson (1988) points out that younger children will have many less mature cognitive skills than older children, and that they may also approach tasks differently due to prior instruction and other learning experiences. With specific reference to literacy development, Thomson suggest that in the early stages of literacy acquisition there tends to be more emphasis on the visual aspect in 'look-and-say' kinds of approaches, whereas as the child gets older there will be more emphasis on 'phonics', that is translating the visual symbols into their sound code or a phonological route to reading. With reference to the developmental theories of spelling, the younger children may still be at the 'logographic' stage (Frith, 1985) which means that they could benefit less from an approach which emphasises naming and segmenting (although some writers, e.g. Goswami and Bryant, 1990, question whether there is a logographic stage in spelling; see also Chapter 2).

A second explanation within the developmental framework comes from the literature on working memory. For example, studies have suggested that children under the age of seven tend to rely more on their visual memory than phonological memory (Hitch, Halliday, Dodd, and Littler, 1989b; Hitch, Halliday, Schaafstal and Heffernan, 1991; Hitch, Halliday, Schaafstal and Schraagen,1988; Hulme, 1987). It is not until after this age that children begin to make more use of their phonological memory even for pictorial information.

Effect of response modality

The studies examined in the previous section suggest that writing is important in helping children of all abilities to learn the spellings of words. More information regarding the importance of writing comes from the study by Treiman and Bourassa (2000), which suggested that by first and second grade, children more accurately represented word spellings when they were able to write the words down as opposed to spelling them orally. The writers hypothesise that this is because writing the words down and thus representing them in a visible form allows the children to more effectively analyse the linguistic structure of a spoken item. However, whether writing is superior to other forms of visually representing words when learning to spell has still not been demonstrated conclusively and only a few studies have specifically examined this issue. The study by Cunningham and Stanovitch (1990) suggested that writing was more effective in helping children learn to spell than either using letter tiles or the computer keyboard. Other studies have not shown this result. For example, the study by Vaughn, Schumm, and Gordon (1993) compared the effects of writing, tracing and using the computer in learning to spell words. Children with and without spelling difficulties took part. The results found no significant differences between the different motoric conditions in the words spelled correctly at post-tests or at follow-up. However, the children were from Grades 3 and 4 and therefore slightly older than in the previous study. The training condition also employed a multi-component training procedure. A study by Berninger et al. (1998) also found no significant overall differences between paper-and pencil and microcomputer instruction. However, none of these studies is directly comparable due to differences in methodologies employed. It is also important to note that these studies did not find that the computer or any other response modality was *superior* to writing in helping children learn to spell, only that there was no difference between different response modalities. More research in this area is needed taking into account factors such as age, ability, proficiency with the computer and writing ability before any conclusions can be drawn on this issue.

Effect of cognitive style

The final study reviewed here does not fit neatly into either of the two main categories of spelling interventions reported in this review. Brooks and Weeks (1998) examined children's differential responses to methods of teaching spelling depending on their cognitive profiles (see also Brooks, 1995; Weeks, Brooks and Everatt, 2002; Brooks, Weeks and Everatt, 2002). Two groups of twelve children with spelling difficulties aged around 14 years old, a dyslexic group of average ability and a group of slow learning children of below average ability, were taught to spell words using a phonics method, a visual method and a tracing method. The phonics method appears to have been an adapted simultaneous oral spelling method, the visual/semantic method was one which drew attention to the whole words and different patterns within the word, and the tracing method required the pupil to trace over the word as if writing it. A third group of twelve children with no spelling difficulties and matched for spelling age (mean age 9.9 years) was used as a control group. The intervention was spread over three weeks with each group being taught a different set of ten words each week using a different teaching method each week.

The results showed that the dyslexic group learned significantly more words with the visual/ semantic teaching method whilst the slow learning children learned significantly more words with the phonics method. The spelling age control group learned equally well under all three methods. The authors conclude that the results suggest that children with different cognitive profiles may respond differently to different teaching methods.

There is a lack of detail in the reporting of the method from this small-scale study. It also does not provide strong evidence of differential responses to teaching strategies depending on cognitive profiles. For example, it is possible that within each of the individual groups there may have been a differential response to the teaching methods. In addition, there appear to be some flaws in the research design such as the reported mean of the spelling age of the children in the slow-learning group being around two years below the means of the other two groups, although the groups were said to be matched for spelling age. More research would be required before any conclusions could be drawn on this issue. However, the study does highlight the need to take into account individual differences when planning the best form of support for a child and it points to an area of research that would benefit from further investigation.

1.3 GENERAL SUMMARY AND CONCLUSIONS

This review has examined interventions designed to help children learn the spellings of words. Before summarising the findings, there are some caveats to note that would qualify any overall comments made from the findings presented. First, not all of the studies addressed the issues of generalisation of strategies learned, or maintenance of words, which are both important in determining any wider and longer-lasting effects. Second, not all of the studies reviewed controlled for words already known, or provided details of how this was done. Third, only seven studies reported sufficient details to allow calculation of effect sizes. However, effect sizes given also have to be treated with some caution. For example, the study with the highest effect size of 1.76 was a treatment comparison study by Darch et al. (2000). Although this was a carefully designed and well-reported study, it used a post-test design which has the disadvantage of not knowing if the groups were comparable in terms of words already known at the start. Effect sizes also cannot be calculated for the single-subject design studies, and the varied methodologies employed make it difficult to directly compare their results. Finally, as noted at the beginning of this review, the techniques and strategies investigated can only be considered to be effective within the context of a broader approach to the development of literacy skills.

These caveats aside, a number of overall comments can be made from the findings of this review. The first is that a critical component of effective instruction is the application of tightly focused, structured and systematic procedures. All of the interventions reviewed here involved the application of such strategies. All reported significant results. In addition, based on Cohen's (1988) criterion of 0.80 as high, 0.5 as medium, and 0.2 as small, effect sizes for treatment comparison studies were quite substantial. The effect sizes ranged from 0.76 to 1.76, with a mean effect size of 1.09. The distribution of these across strategies precluded more detailed comparison by meta-analysis. Overall, this review provides strong evidence that a range of different structured, systematic and skill-focused strategies can be effective in helping children learn to spell. These include immediate error correction by self-correction, imitation/modelling, distributed practice and reduced word-list size, analogy training, rule-based instruction, systematic study procedures, multisensory strategies and phonemic instruction

A second comment is that the studies reviewed here provide evidence that writing is a critical element of effective learning for children of all abilities. However, for struggling readers and spellers, more elaborated multisensory strategies such as those involving saying the word out loud or saying each letter name out loud as it is written have also been shown to be effective. There is also some evidence to suggest that such strategies may not significantly enhance the ability of normally developing readers and spellers to learn the spellings of words, although the evidence presented on this point cannot be regarded as definitive.

A third and final comment is that this review has provided evidence to show that students with spelling difficulties often fail to use appropriate strategies to learn the spellings of words. However, it has also shown that not only can students be effectively taught systematic spelling study strategies but that they are also able to apply these strategies independently. It has also highlighted the importance of providing students with lots of opportunities to generalise skills learned through application in day-to-day practice. In summary, this review has provided empirical evidence for the effectiveness of a range of different instructional techniques and word-study strategies that require no extra resources and few additional demands on time that students can be taught to use to enhance their spelling skills.

The next chapter will approach spelling from a theoretical perspective, looking at how spelling skills are thought to develop in children as well as the cognitive factors that may underpin the processes of spelling.

CHAPTER 2. A COGNITIVE FRAMEWORK FOR SPELLING

Spelling is a complex skill involving a range of cognitive and linguistic processes. This chapter will consider the main cognitive processes that are thought to be important for spelling and spelling development. It will begin by presenting a broad perspective on spelling, outlining the major models and theories that have been derived from different research fields, namely, developmental, cognitive and computational. It will then go on to explore what are considered to be some of the critical cognitive processes underpinning spelling. There will be an emphasis here on the role of working memory in spelling and how this might interact with other processes to support spelling. It will be argued that much of what is known about working memory and other phonological processes in spelling remains unclear and that much more research in this area is needed.

2.1 THEORIES OF SPELLING

2.1.1 Developmental Models

Developmental theories of spelling (e.g. Ehri, 1987; Gentry, 1982; Henderson, 1990) describe how children's knowledge of spelling evolves. These theories have been derived largely from the early work of Read (1975, 1986) and Chomsky (1979) into how young children create or invent spellings, together with a body of developmental spelling research by Henderson and colleagues at the University of Virginia during the 1970s and 1980s (see Gentry, 2000, for a retrospective).

Stage theories of spelling view the development of spelling skills as passing through a series of phases reflecting the knowledge sources used by children. The stages or phases are variously described as precommunicative, semiphonetic, phonetic, transitional, and conventional (Gentry, 1982), prephonetic, semiphonetic, letter name, within-word pattern and syllable juncture (Bear and Templeton, 1998), or precommunicative, semiphonetic, phonetic and morphemic (Ehri, 1987). However, although there may be differences in terminology, all of the models suggest a gradual shift in children's understanding of the English spelling system, from a very simple view to an increasingly more in-depth understanding of its complexities. Frith describes these stages more broadly as the logographic, alphabetic and orthographic stages (Frith, 1985), reflecting a transition from a reliance on visual memory for patterns, to an understanding of phonemic decoding, to a final stage where more complex rules of orthographic structure are understood and utilised.

Ehri (1987, 1997) provides some examples of how children's spelling may evolve throughout these stages. She discusses how at the precommunicative stage children may produce scribbles for words, or randomly selected or copied letter strings. At the semiphonetic stage children then begin to use acquired knowledge of letter names and sounds to write words, e.g. *yl* for while; *lefunt* for elephant. The next stage (phonetic) sees children beginning to make more accurate use of letter-sound relationships, with most irregular words written as if they were phonetically regular, such as *sed* for said. They may also stretch out the sounds in words, finding extra sounds not symbolised in conventional spellings, for example, *balaosis* for blouses. In the final stages, children demonstrate a more sophisticated understanding of word structure and become more confident in using commonly occurring letter strings and in spelling by analogy, such as *beak* and *leak* (Ehri, 1987).

It is argued by some researchers that the development of children's spelling is more complex, and more continuous, than stage models would suggest. For example, there is growing evidence to suggest that children apply knowledge of orthographic and morphological principles much earlier in spelling than first believed (e.g. Bryant, Nunes and Bindman, 1997; Cassar and Treiman, 2004; Goswami, 1988; Rittle-Johnson and Siegler, 1999; Varnhagen, McCallum and Burstow, 1997). Such theories suggest that children use a range of different strategies and types of linguistic knowledge (e.g. phonological, orthographic, morphological and semantic) in interaction with each other and with increasing efficiency across time (e.g. Rittle-Johnson and Siegler, 1999; Treiman and Bourassa, 2000).

2.1.2 Cognitive Models

Cognitive models of spelling address the actual processing steps involved in the task of spelling production. Evidence from patients with neurological damage affecting their writing and spelling (e.g. Beauvois and Dérouesné, 1981: Rapp and Caramazza, 1997; Roeltgen, Sevush and Heilman, 1983; Shallice, 1981) supported by recent neuroimaging studies (Norton, Kovelman and Petitto, 2007) suggests that there are two main spelling routes which may be used when spelling. This evidence led to the development of dual-route models of spelling (see Roeltgen and Rapcsak, 1993, for a historical perspective of the development of these models). Dual-route models of spelling distinguish between the processes that may be used for spelling of familiar words, the lexical route, and those used for spelling words that are unfamiliar, the sub-lexical or phonological route (e.g. Barry and Seymour, 1988; Caramazza, Miceli, Villa and Romani, 1987; Ellis, 1982; Kreiner, 1992; Margolin, 1984; Patterson, 1986). These models are similar to dual-route models developed for reading (e.g. Coltheart, Curtis, Atkins and Haller, 1993).

Figure 1 shows a schematic representation of the spelling process as described by dual-route models. The basic premise of these models is that the lexical route retrieves information about words, or parts of words, from a long-term memory store commonly referred to as the orthographic output lexicon (Barry, 1994). Unfamiliar words or nonwords utilise a non-lexical or phonological route that makes use of stored knowledge of the regular relationships between sounds and letters and phoneme-grapheme rules to assemble words (Ellis, 1982; Barry and Seymour, 1988; Kreiner, 1992). Once a spelling has been either assembled or lexically retrieved it is then held is what has been termed a response buffer (e.g. Morton, 1980, Wing and Baddeley, 1980), now more commonly referred to as a graphemic buffer (Roeltgen and Rapcsak, 1993) while output processes are being prepared and implemented.

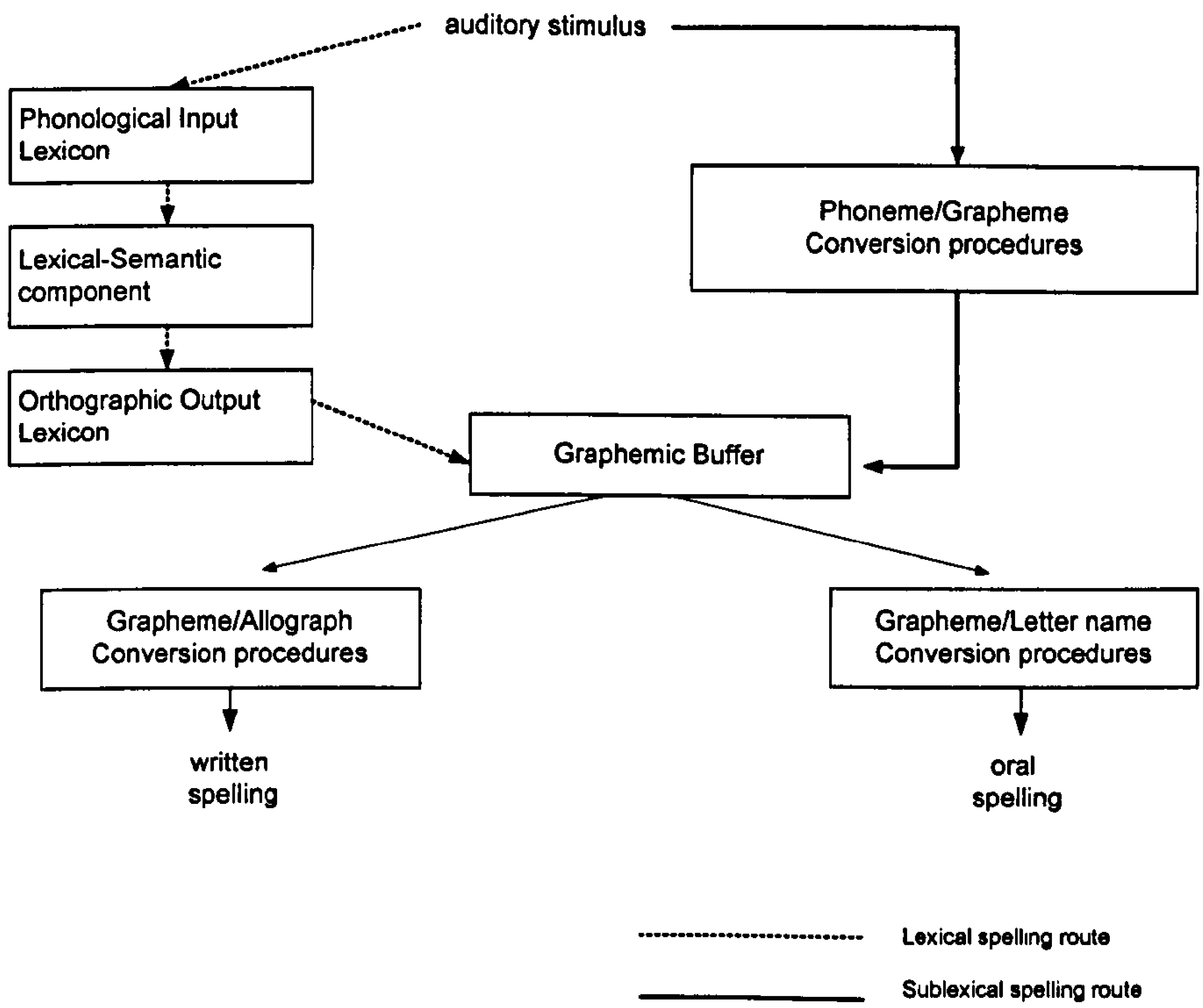

Figure 1. The Dual-Route Model of spelling production (adapted from Miceli and Capasso, 2006).

At present, there is still an incomplete understanding of the cognitive processes and neural systems involved in these spelling routes (Norton et al., 2007) and many key issues remain unclear, such as the quality and type of representations held in the graphemic buffer as well as its capacity (Service and Turpeinen, 2001). Also, although both spelling routes are thought to be independent in that neither requires the other and each can be lesioned independently (e.g. Beauvois and Dérouesné, 1981; Shallice, 1981), there is evidence from studies involving subjects with no spelling impairments (e.g. Barry and Seymour, 1988; Campbell, 1983) and subjects with dysgraphia (Hillis and Caramazza, 1991) to suggest that both routes can interact during the spelling process. Currently, there appears to be general agreement that the routes work in parallel, with the two sources of information competing or converging to various degrees (e.g. Kreiner, 1992). However, there is no general consensus on the precise nature of these systems or routes and the relationships between them, and work in this area is ongoing (e.g. Miceli and Capasso, 2006; Rapp, Epstein and Tainturier, 2002). The recent neuroimaging study by Norton et al. (2007) showed more widespread brain activity during the spelling of nonwords that was different from the activity exhibited by spelling real words (either regular or irregular). The authors suggest that nonwords may access both a lexical and a non-lexical route, looking for similar words that are stored as whole lexical units as well as attempting to assemble the correct representations from sublexical/phonological units.

Studies examining children's spelling have shown that children appear to make use of different routes when spelling depending on whether the word is a regular or nonword or an irregular word (Treiman and Baron, 1983; Varnhagen at al., 1997) suggesting that the dual-route model of spelling is applicable to children. Bryant and Bradley (1980) showed that many children go through a period in spelling development when they demonstrate the ability to correctly spell but not to read highly regular words. In contrast, irregular words can often be read but not spelled correctly. As children's skills develop, there are many fewer words that they can spell but not read. Bryant and Bradley's study suggests that lexical and sublexical processes in spelling may develop separately and at different times during spelling acquisition, and also that the timing of these stages may differ somewhat between spelling and reading. This is in line with Firth's (1985) interactive model of the stages of reading and spelling development which proposes that each of the stages in reading and spelling may develop out of step with each other, with a corresponding mutual influence on each other. The dual route model therefore has important conceptual links with developmental stage models of literacy. The model can also be used to account for developmental disorders of spelling. For example, Frith hypothesises that classic developmental dyslexia could be conceptualised as an over-dependence on a lexical spelling route, stemming from an inability to acquire alphabetic reading or spelling strategies.

2.1.3 Computational Models

Computational models of spelling using a 'connectionist' framework provide a very different view of the spelling process. Connectionist models are designed to simulate the processes taking place in the brain during mental activities and describe cognitive processes as the result of the activity of densely interconnected networks of simple units (corresponding to neurons). The models are designed to be tested on the computer and to learn from exposure to examples using the 'back-propagation learning algorithm' (Rumelhart, Hinton and Williams, 1986, cited in Christiansen and Chater, 2001). In a typical connectionist network, the units operate cooperatively and simultaneously to process information. Units tend to have an activated value of between 0 and 1. The connections between the units are key elements in that they permit the level of activity in any one unit to influence the activation of all the units that it is connected to. The connection strengths can be adjusted by a suitable learning algorithm or rule in order to instigate a particular pattern of activation which leads to a desired outcome, and it is this ability to adjust which allows the programme to learn (Christiansen and Chater, 2001).

Although spelling has not received the same attention as reading, a number of connectionist models have been proposed, using architecture similar to those of the reading (e.g. Seidenberg and McClelland, 1989) models. For example, Brown and Loosemore (1994), Bullinaria (1994) and Olsen and Caramazza (1994) all describe models of sound-spelling conversion using single-route multilayer networks. Dual-route multilayer models have also been proposed by Rapp et al. (2002) and Houghton and Zorzi (2003).

Brown and Loosemore (1994) give a simple account of the advantages of connectionist models over verbally expressed models. The first is the precision with which the model needs to be expressed in order to guarantee that it is workable (that is, it needs to include all the knowledge and mechanisms necessary for the system to perform the task it is designed for). Second, the models can be confirmed (or disconfirmed) as well as adapted and expanded through systematic exploration under simulated conditions. Finally, the authors suggest that due to the precision with which the model is described both in terms of its processes and the terminology used it is possible for anyone to examine or recreate the programme for further exploration.

2.2 COGNITIVE PROCESSES UNDERLYING SPELLING DEVELOPMENT

The dominant view that has been developed over the last thirty years is that the key cognitive processes underlying children's development in basic literacy skills are phonological processing abilities (e.g. Goswami, 2002; Hulme, Snowling, Caravolas and Carroll, 2005; Muter, 1994; Share 1995; Vellutino and Scanlon, 1987; Goswami, 2002; Pennington, Cardoso-Martins, Green and Lefly, 2001). Phonological processing is a broad term that is used to describe abilities that all share a common factor, which is the ability to use information about the sound structure of oral language in learning how to read and write (e.g. Wagner and Torgesen 1987).

Research into phonological processing and literacy development continues to attract a great deal of interest. However, there is still no consensus as to which abilities may be best captured by this umbrella term or about the relative importance of these abilities for the development of reading and spelling skills. This is particularly true in the case of spelling, which in comparison with reading has received very little attention in the literature. Where spelling has been assessed, it has often been included in a composite measure of literacy (e.g. Ackerman, Holloway, Youngdahl and Dykman, 2001; Gathercole et al., 2006; Rohl and Pratt, 1995). However, some correlational studies have included independent assessments of spelling (e.g. Cormier and Dea, 1997; Cornwall, 1992; McCallum et al., 2006; Pennington et al., 2001; Savage et al., 2008; Savage and Frederickson, 2006; Savage et al., 2005; Tijms, 2004). The research by Savage, Frederickson and colleagues in particular has helped to fill some gaps in the literature in relation to the cognitive factors that may be important for spelling development, reporting some distinct patterns of associations that have not been reported elsewhere. The findings from all of this research together with those of longitudinal studies that have explored the development of both spelling and reading together (e.g. Bradley and Bryant, 1985; Caravolas, Hulme and Snowling, 2001; Juel et al., 1986; Lundberg, Frost and Peterson, 1988; Scarborough, 1998) suggest that the patterns of relationships between the cognitive factors that may underlie spelling and those that are thought to underlie reading may be somewhat different. As reading and spelling are very closely connected (e.g. Ehri, 1997), any differences that are found will be important to help further our understanding of how these skills develop. The next sections in this review will examine the relevant studies which have explored cognitive processes in spelling. Where possible, comparisons will be drawn between the findings for spelling and those that have been reported for reading either in the same study or elsewhere in the literature.

Search procedures

Studies for possible inclusion in this section of the literature review were located using the database PsychINFO and the search engines Google Scholar and Advanced Scholar. The search terms used included *spelling, literacy, working memory, short-term memory, phonology, phonological processing, cognitive factors, RAN,* and *phonological awareness* in various combinations. Additional studies were located by tracking citations from relevant articles and from these articles' reference lists. Studies published in both peer reviewed journals and in books were considered. The criteria for inclusion in this review were that studies should have examined the relationship between at least one cognitive factor and spelling and that they involved typically developing children or children with specific learning difficulties of a dyslexic nature. However, some key studies involving adult populations were also included (e.g. Ormrod and Cochran, 1988). Studies involving children with acquired impairments (e.g. as a result of brain injury) and other impairments such as speech and language difficulties or sensory impairments were excluded.

In order to facilitate comparisons between some of the research findings for spelling and those for reading, studies examining a range of phonological processing factors and reporting findings for both reading and spelling (e.g. Cormier and Dea, 1997; Cornwall, 1992; McCallum et al., 2006; Pennington et al., 2001; Savage and Frederickson, 2006; Savage et al., 2005; Scarborough, 1998; Tijms 2004) have been presented in schematic form in Table 2.[1] However, it is important to emphasise that not all of the key spelling studies that are discussed in this chapter are included in this table.

2.2.1 Terminology on working memory

Several models of working memory have been proposed (see Chapter 3), and the terminology used to describe working memory concepts can be confusing. Working memory is a term which is generally used in cognitive psychology to describe an active memory system that is responsible for the temporary storage and simultaneous manipulation of information (Bayliss et al., 2005). In contrast, the related concept of short-term memory (STM) is used to refer to a system or systems which are specialised purely for the temporary storage of information within particular domains (Dehn, 2008; see Gathercole, 1998, for a comprehensive review of the developmental literature on WM and STM). However, this distinction is not always clear-cut, the precise usage of each of the terms tending to vary depending on the theoretical perspective which has been adopted.

The terminology which is adopted here is consistent with the Baddeley and Hitch multi-component model of working memory (e.g. Baddeley, 2001; Baddeley and

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[1]The studies summarised in this table have reported results for a range of spelling and reading-related outcomes. These include word spelling production, spelling recognition, word reading, reading comprehension and reading fluency. In order to make comparison between studies more meaningful, only the results for word reading and word spelling are reported here.

Hitch, 1974). This model describes four components of working memory: the phonological loop which holds information in a phonological code, the visuospatial sketchpad which stores visual/spatial information, the episodic buffer which binds information from different sensory modalities and maintains this in a multidimensional code, and the central executive, which controls and regulates the working memory system.

In this chapter and throughout the remainder of this thesis, the following terms will be used. *Memory* will be used as a general, non-specific term. *Working memory* (WM) will be used when referring to the complete working memory system. However, *working memory* will also be used when making specific reference to storage plus processing components of the system as opposed to *short-term memory* (STM), which will be used to denote storage only components, for example, verbal short-term memory and verbal working memory. Attention will be drawn to the precise meaning of working memory where it may not be clear from the context. The terms *simple* and *complex* will be used when referring to tasks that are designed to measure storage only and storage plus processing memory components respectively. The term *phonological memory* is used extensively in the literature. Throughout this study, and in line with previous researchers (e.g. Gathercole and Baddeley, 1993), this term is used synonymously with verbal short-term memory.

2.2.2 Dimensions of Phonological Processing

Wagner and Torgesen (1987) have described three separate but interrelated dimensions of phonological processing which have been shown to be important for the acquisition of literacy skills, each emanating from largely independent bodies of research. These are phonological awareness, phonological coding in working memory and phonological retrieval (see also Wagner, Torgesen and Rashotte, 1994; Wagner, Torgesen, Laughon, Simmons, and Rashotte, 1993, for studies detailing results of factor analysis of these dimensions).

Phonological awareness is said to represent an explicit phonological process requiring reflection on and usually manipulation of the phonological components of spoken words (Gombert, 1992). Such abilities are normally demonstrated in tasks that vary in levels of difficulty, such as knowledge and awareness of rhymes, phoneme deletion or substitution tasks or nonword reading (for reviews see Adams 1990; Snowling, 2000). In contrast, the remaining two dimensions have been described as implicit phonological processes as they are said to represent cognitive processes that engage speech codes without conscious awareness (e.g. Clarke, Hulme and Snowling, 2005). Phonological retrieval is also known by the term rapid automatic naming (RAN). Rapid automatic naming is a measure of naming speed. RAN tasks require participants to name arrays of familiar items – letters, digits, colours or objects – as quickly as they can (Denckla and Rudel, 1976). Phonological coding in working memory is not precisely defined in the literature but generally refers to verbal short-term memory (Wagner and Torgesen, 1987).

2.2.3 Ongoing Research Paradigms

Savage and Frederickson (2006) describe two broad approaches into investigations into literacy development and literacy difficulties. One approach has been to examine the extent to which phonological processing can be considered as a set of distinct functions, such as phonological awareness, rapid automatic naming and working memory, each of which exerts an independent effect on reading and spelling development, or if these processes may be better understood within a broad phonological core factor. A second approach has been to explore the neurological and developmental origins and precursors of phonological language processes (e.g. Annett, 1998; Beaton, 2004; Scarborough, 1990; Tallal, Miller, Jenkins and Merzenich, 1997). Theories emanating from both these lines of research can be considered as complementary to each other, each adding contributions at different levels to increase our understanding of the causes of reading difficulties (Frith, 2002).

A discussion of the developmental origins of literacy is not the remit of this study and only the role of phonological processing factors in relation to literacy development will be considered further here.

2.2.4 Underlying Theories

The Phonological Representations Hypothesis

One of the most influential hypotheses that has been proposed to help conceptualise difficulties in phonological processing is that these difficulties arise in the main from weak phonological coding leading to poorly specified or inaccurate phonological representations (e.g. see Brady, 1997; Hulme and Snowling, 1992; Muter, 1994; Swan and Goswami, 1997). It is the quality of these representations that in turn affects children's ability to develop literacy skills.

The phonological representations deficit hypotheses is said to account for a range of phonological processing difficulties. For example, weak phonological coding might result in inefficient phonological loop processes and thus reduced verbal short-term memory capacity. It could also lead to impairment in phonological sensitivity and phonological awareness (Brady, 1997; Goswami, 2002). Retrieval of phonological information from long-term memory could also be hampered by the difficulty in establishing fully specific phonemic representations of words (Elbro, 1996). An alternative explanation that has been suggested is that the phonological deficit is related to processing speed (e.g. Shankweiler, Crain, Brady and Macaruso, 1992), that is, slow processing of phonological information could result in a bottleneck that impedes the transfer of information to higher levels of processing within the working memory system. Both of these perspectives, however, suggest that the core problem for poor readers is a deficit in phonological processing.

The Double-Deficit Hypothesis

Not all researchers agree that a single phonological core deficit is sufficient to explain some children's difficulties with reading and spelling. In particular, Wolf and Bowers (e.g. Bowers and Wolf, 1993; Wolf and Bowers, 1999) have suggested an alternative view which proposes that lexical retrieval deficits represent a second core deficit that is largely independent of phonology. Lexical retrieval or rapid automatic naming (RAN) is measured by tasks that require participants to name arrays of familiar items – letters, digits, colours or objects – as quickly as they can. It is suggested that RAN tasks are more related to orthographic than phonological factors, and that performance on these tasks is linked to the quality of underlying orthographic representations (Bowers and Wolf, 1993). Wimmer, Mayringer and Landerl (1998) suggest that RAN is an index of how well children can establish the word-specific orthographic representations that underlie reading.

As a result of evidence suggesting that both phonological awareness and naming speed may be unique contributing variables to reading (e.g. Ackerman and Dykman, 1993; Badian, 1993; Cornwall, 1992: Scarborough, 1998; for review see Wolf, Bowers and Biddle, 2000), Wolf and Bowers have proposed a 'double-deficit' hypothesis of reading disability. This hypothesis depicts phonological processes and the processes underlying naming-speed deficits as being two largely independent sources of reading dysfunction, resulting in three subtypes of reading impairment. These three subtypes are characterised, respectively, by phonological deficits, naming-speed deficits, and a combination of both. Moreover, it is proposed that these deficits are additive and will produce more severe reading difficulties when they co-occur in the same child (see Compton, DeFries and Olson, 2001; also Vellutino, Fletcher, Snowling and Scanlon, 2004, for critique).

2.2.5 The Role of Phonological Processes in Spelling

Phonological Awareness

The strong relationship between phonological awareness and the development of reading skills is well-documented in the literature (for reviews see Adams 1990; Blachman, 2000; Brady and Shankweiler 1991; Goswami and Bryant 1990; Muter, 1994; Wagner and Torgesen, 1987). Although research investigating the relationship between phonological awareness and spelling has not been as prolific as that for reading, there is still a considerable amount of evidence to suggest that phonological awareness is as important for spelling development as it is for reading (e.g. Bradley and Bryant, 1983, 1985; Compton et al., 2001; Cormier and Dea, 1997; Griffith, 1991; Juel et al.,1986; Lundberg et al., 1988; Muter et al., 1998; Pennington et al., 2001; Savage and Frederickson, 2006; Savage at al., 2005; Savage et al., 2008; Scarborough, 1998; Stuart and Masterson, 1992). The seminal research by Bradley and Bryant (1983) followed two groups of pre-reading children, nursery children aged around 4 years of age and primary children aged around 5 years of age (see also Bradley and Bryant, 1985, for full details of this research). Moderately strong correlations were obtained between the phonological awareness scores of the 4- and 5-year-old children and their spelling levels over three years later (0.48 and 0.44 respectively). Regression analysis showed that phonological awareness accounted for 8.1% and 5.6% of the variance in spelling for these year groups after controlling for IQ, verbal ability and short-term memory. These figures are comparable with those obtained for reading, although there were slightly stronger associations shown for the 4-yr-old children for reading and slightly weaker associations for the 5-yr-olds (9.9% and 4.1% of the variance respectively). The study by Juel et al. (1986) also showed that phonological awareness was the best predictor of spelling and reading in the first two years of school, after controlling for IQ and listening comprehension. Another important finding from the Bryant and Bradley study was that the children who received training in phonological awareness performed significantly better than control groups on spelling (and reading) measures following the training (see also Lundberg et al., 1988).

Regarding the relative importance of phonological awareness for spelling compared with reading, there is evidence to suggest that phonological awareness may be more related to spelling than to reading at the very early stages of literacy development. The importance of phonological strategies in young spellers has been documented in the pioneering work of Read (e.g. Read, 1971; 1986) on children's invented spellings (see also e.g. Treiman and Bourassa, 2000). In contrast, the use of visual strategies in early reading was suggested in the work of Barron and Baron (1977) which examined how children extract meaning from printed words. This study argued that when children initially learn to read they recognise words as whole visual patterns or chunks rather than using a phonetic code. Subsequent research has confirmed the use of visual strategies by beginning readers (e.g. see Ehri, 2005, for discussion). Further evidence of differences between the strategies used for spelling and those used for reading by beginning readers and spellers comes from a study by Bryant and Bradley (1980). This study provided evidence to show that in the early stages of literacy development, children were sometimes able to spell phonetically regular words like 'leg' even though they might not be able to read them (but see Stuart and Masterson, 1992) and also to read words they could not spell. However, by about the age of 10 years of age there were very few words the children could spell but could not read. The authors suggested that this may be because initially children rely on a direct, visual route for reading and an indirect, phonological route for spelling. However, as their skills develop children begin to use both strategies as well as other linguistic, and in the case of reading, contextual cues. These findings support both the dual-route models of spelling and stage theories of spelling development discussed earlier.

Results of training studies also highlight the importance of phonological awareness for early spelling. The study by Bradley and Bryant (1981) discussed earlier showed that training in sound categorization actually had a much greater effect on spelling (17 months' gain) than on reading (8.5 months' gain). Lundberg, Frost and Petersen

(1988) trained over 200 Danish preschool children in phonological awareness and assessed the later effects on reading and spelling in the first and second grade. This training had a large effect on Grade 1 spelling ($p<0.001$) but only a marginal immediate effect on Grade 1 reading ($p<0.01$). By the end of Grade 2 the effect of training on spelling had persisted ($p<0.001$) and the effect on reading was becoming stronger ($p<0.01$), also confirming the importance of phonological awareness for reading.

Other studies also provide some evidence that phonological awareness may be more important for early spelling than for early reading. The longitudinal study of Swedish children in Grades 1 and 2 by Tornéus (1984) reported that the relationship between phonological awareness was stronger for spelling than for reading at all three assessment points during the study. Cataldo and Ellis (1988) found that phonological segmentation skills predicted spelling during the first three years at school (see also Ellis and Cataldo, 1990). The same measures accounted for growth in reading skills only in the second year of school.

There is evidence to suggest that there may be other factors that combine with phonological awareness to make it especially important for spelling. For example, the study by Juel et al. (1986) showed that phonological awareness, cipher knowledge (i.e. knowledge of letter-sound correspondences) and exposure to print, all interacted in the development of spelling and reading. It has been argued that letter-sound knowledge may be more important for spelling than for reading initially in that spelling requires production of the exact letter and sequence of letters, whereas reading requires recognition which can also be supported by contextual cues (Perfetti, Beck, Bell and Hughes, 1987). It may be therefore that it is phonological awareness in combination with letter knowledge and possibly other factors that may be primary for early spelling. Some support for this comes from the study by Muter et al., (1998; see also Caravolas et al., 2001). This study showed that phonological awareness skills (measured by segmentation tasks) and letter knowledge predicted both reading and spelling in the first year of school. These skills operated in an independent and additive manner. However, there was an additional interactive effect which was small for reading but large for spelling. Phonological awareness continued to predict spelling in the second year of school. The children in this study were all typically developing children selected at random from nursery schools. This study supports others that have identified the crucial importance of phoneme segmentation skills for the development of spelling (e.g. Bryant, MacLean, Bradley and Crossland, 1990; Cataldo and Ellis, 1988: see also Goswami and Bryant, 1990). There is now a large body of evidence to show that specific training in phoneme segmentation skills and instruction in letter sound knowledge significantly improves children's spelling skills (e.g. Ball and Blachman, 1991; Foorman, Francis, Novy and Liberman, 1991; Castiglioni-Spalten and Ehri, 2003; Cunningham, 1990; Lundberg et al., 1988; Bradley and Bryant, 1983, 1985; Ehri and Wilce, 1987; Uhry and Shepherd, 1993).

Studies of older children suggest that phonological awareness continues to be a significant predictor of spelling as children's spelling skills develop (e.g. Compton et al., 2001; Cormier and Dea, 1997; Pennington et al., 2001; Savage and Frederickson, 2006; Savage et al., 2005). However, the study by Tijms (2004) involving Dutch children aged between 10 and 14 years of age did not find phonological awareness to be a significant predictor of spelling. It is possible that this result might reflect both the age of the children in this study and the greater degree of transparency of the Dutch language compared with English. It has been suggested that in shallow orthographies such as German (or Dutch), phonological awareness difficulties appear to be more transient than in English and that children appear to have overcome these difficulties by the end of their second year in school (Goswami, 2002; Wimmer, 1993). Goswami (2002) suggests that it is the relatively consistent feedback from grapheme-phoneme relations in shallow orthographies that provides beginning readers with more opportunities to develop an adequate level of phoneme awareness. Tijms (2004) notes that it is possible that phonological awareness might have had an impact in the early stages of reading for the participants in his study.

There is some evidence to suggest that phonological awareness may be more important to spelling than to reading for older children who are poor readers. For example, the longitudinal study by Scarborough (1998) reported that phonological awareness made a significant contribution to spelling but not to reading in poor readers at age 14. For good readers the best predictors of spelling were the children's literacy scores at Grade 2. A larger contribution made by phonological awareness to the variance in spelling compared with reading in poor readers has also been shown in other studies (e.g. Cornwall, 1992; Pennington et al., 2001). However, these studies are not directly comparable given their different designs. The study by Savage and Frederickson (2006) reported that average and below-average readers differed significantly in their phonological awareness abilities, as did average and below-average spellers. However, the effect sizes for these differences within the reading and spelling groups were of the same magnitude (see Table 2). Overall, there appears to be no clear evidence regarding the relative importance of phonological awareness for spelling development compared with reading in older children.

Summary

Studies have shown that phonological awareness both independently and in combination with letter knowledge is highly important for spelling development both in the early stages and as children's skills develop. There is also some evidence to suggest that these factors may be more important initially for spelling development than for reading development and that phonological awareness may be more important to spelling than to reading for poor readers. However, few studies have specifically explored these latter issues and more research is needed before any conclusions can be drawn.

Rapid Automatic Naming and Spelling

Only a small number of studies have explored the relationship between RAN and spelling (e.g. Compton et al., 2001; Sunseth and Bowers, 2001; Cornwall, 1992;

Pennington et al., 2001; Scarborough, 1998; Strattman and Hodson, 2005; Savage et al., 2008; Savage et al., 2005; Savage and Frederickson, 2006). Findings from these studies have been mixed. Some studies, for example Cornwall (1992) and Pennington et al. (2001) have reported no unique contribution of RAN to the variance in spelling beyond the contribution of phonological awareness. Both these studies reported RAN effects for reading. Others have found that RAN is a unique predictor of spelling even when other phonological factors are taken into account. The longitudinal study by Scarborough (1998) examined the relationships between a range of cognitive factors and the reading and spelling outcomes of 55 children tested at 8 years old (Grade 2) and 14 years old (Grade 8). The study found that RAN, phonological awareness and verbal STM were all associated with reading and spelling abilities at both grade levels. However, RAN was the best predictor of spelling at Grade 8 for the poor readers and spellers, although phonological awareness also made an additional contribution. In this study RAN was also the best predictor of reading for the poor readers, but here phonological awareness did not make an additional contribution.

Unique contributions of RAN to spelling have also been reported in a number of correlational studies (e.g. Compton et al, 2001; Strattman and Hodson, 2005; Savage et al., 2005; Savage et al., 2008). All of these studies also reported a much greater contribution from phonological awareness. In the study by Savage et al., (2005) involving 61 typically developing children aged between 7 and 10 years old, RAN was found to contribute unique power to the discrimination of below-average from average spellers and also to discriminate below-average from average readers. A regression analysis using the whole sample found that RAN was also an overall predictor of spelling when other phonological variables had been taken into account, adding an additional 6% of the variance. Phonological awareness was the best predictor, adding a highly significant 26% of the variance. However, RAN was not found to be an overall predictor of reading. These results suggest that RAN remains an important concurrent predictor of performance in spelling for all children as their literacy skills develop. However, the findings for reading reported here are similar to those of other studies where RAN effects have been demonstrated in poor readers but not good readers (e.g. Scarborough, 1998; Meyer, Wood, Hart and Felton, 1998).

Further support for a strong association between RAN and spelling comes from the study by Savage and Frederickson (2006). The performance of groups of average- and below-average readers and average- and below-average spellers on RAN tasks was compared. Analysis of effect sizes found that there was a moderate effect size for differences in digit RAN between the two reading groups (ES= 0.76). However, a strong effect size (ES= 1.32) was reported for differences in digit RAN between the two spelling groups.

The findings from the studies just discussed, although slightly mixed, suggest that different patterns of associations may exist for RAN and spelling than for RAN and reading. Further information on this issue comes from a recent study by Savage et al. (2008). This study involved 65 children with specific literacy difficulties aged between 7 and 13 years old. To the writer's knowledge, this is the only published study to date that has been specifically designed to explore RAN-spelling associations. In this study, Savage and colleagues argue that in order to clarify the nature of RAN-spelling associations, pseudoword spelling has to be controlled for, which the writers state has not previously been done. The rationale behind this argument is that there are different degrees of consistency between pronunciation and print in English spelling compared with reading. For example, it has been shown that feedforward inconsistency, which is where a rime body spelling has more than one pronunciation (e.g. *–eaf*, in the words *leaf* and *deaf*) was rated as 30.7% for monosyllabic words in English, whereas feedbackward inconsistency, which is where a rime pronunciation has more than one spelling (e.g. /u/ in new, shoe, and brew) was rated at 72.3% for all monosyllabic words in English (Ziegler, Stone and Jacobs, 1997; cited in Savage et al., 2008). Savage et al. argue that this suggests that many more words are decodable in English for reading than for spelling and that spelling might therefore be conceived of as reflecting a more orthographic learning task. They further suggest that the use of pseudoword spelling would control for the ability to use sublexical spelling processes, namely, the use of phonological strategies and spelling rules. Any additional variance added by RAN measures after controlling for pseudoword spelling could therefore be considered to reflect the capacity to learn word-specific phonological labels for orthographic information.

This study by Savage et al. (2008) compared the results obtained from an analysis controlling for nonword spelling and one that controlled for nonword reading. Nonword reading was used because this is thought to be a relatively pure measure of the capacity to apply metaphonological subskills to print (e.g. Rack et al., 1992). The results of a regression analysis showed that after controlling for age and non-verbal ability, nonword spelling explained a very large amount of the variance in spelling (a unique 23%). However, there was also a significant additional contribution from letter and digit RAN of 10% and 8% of unique variance respectively. When nonword spelling was replaced with nonword reading, nonword reading explained a highly significant 30% of unique variance in spelling. However, the effects of letter and digit RAN were reduced to 5% (significant at the .05 level only) and 1% (NS) respectively. The researchers argue that these results show that the use of theoretically derived spelling to sound measures reflect the robust effects of RAN as a measure of the capacity to apply orthographic processing skills as opposed to sound-spelling rules. This study also showed that letter RAN contributed a modest additional unique variance to reading of 6%, supporting other studies that have demonstrated an effect of RAN on reading amongst poor readers.

Finally, some studies have also reported differences between the effects of alphanumeric RAN tasks (digits, letters) and non-alphanumeric tasks (e.g. pictures, colours). However, reported results have not been consistent, with some studies reporting effects only for alphanumeric tasks (e.g. Savage et al., 2006; Savage et al, 2008) and others that there is no difference (e.g. Pennington et al, 2001).

Summary

There is gathering evidence that RAN may contribute significantly to literacy development beyond the contribution of other phonological variables such as phonological awareness. However, the results remain equivocal. Within the reading research literature, it has been suggested that a number of factors could influence research findings, such as the age of the participants and the severity of the reading difficulty (e.g. McBride-Chang and Manis, 1996; Meyer et al., 1998). It is likely that these issues would also apply to findings for RAN-spelling. However, there is some evidence beginning to emerge from the spelling research to suggest that there may be some differences between the pattern of associations` between RAN and spelling and RAN and reading. It has been argued by Savage et al. (2008) that there may be quite specific RAN-spelling associations reflecting ability to access orthographic information about words, and that these can be shown up most clearly when controlling for pseudoword spelling in any analysis. This is an important finding which clearly would benefit from further research. Overall, however, the precise nature of the associations between these RAN variables and both spelling and reading development remains a matter of much debate.

Working Memory and Spelling

According to Hatcher and Snowling (2002), the most consistently reported phonological difficulties found in children and adults with literacy difficulties are limitations in verbal short-term memory. This is borne out by the large body of evidence that has accumulated which suggests that there is a strong relationship between verbal memory and reading (e.g. de Jong, 1998; Gathercole et al., 2006; Jorm, 1983; Leather and Henry, 1994; Rapala and Brady, 1990; Siegel and Ryan,1989; ; St Clair-Thompson and Gathercole, 2006; Swanson and Ashbaker, 2000; Swanson and Jerman, 2007; for reviews see Jorm, 1983; Elbro, 1996; Pickering, 2004; also Savage, Lavers and Pillay, 2007, for a recent critique on the research examining the relationship between working memory and reading). However, despite this plethora of research, very few clear and unequivocal findings have emerged regarding the extent to which various components of working memory are critical for successful reading development.

In contrast with the research into reading, very few studies have examined working memory and spelling and as a result even less is certain about this relationship. Existing studies will now be reviewed. All of the discussion which follows will assume as a framework the multi-component model of working memory of Baddeley and Hitch (e.g. Baddeley, 1986; Baddeley and Hitch, 1974: this model will be discussed fully in the next chapter), as this model has been formed the theoretical basis of the majority of research carried out.

Verbal memory

In the study by Cataldo and Ellis (1988) which examined interactions in the development of spelling, reading and phonological skills, it was shown that when children begin to learn to spell they first attempt to articulate the sounds in the words they hear before they write the corresponding letters. The researchers suggested that this points to an interaction between the phonological loop via articulation and the ability to hear and segment words into constituent phonemes, that is, phonological awareness. They further argued that the study highlighted the importance of verbal ST memory as well as phonological awareness for very early spelling, suggesting that it is through articulation that beginning spellers forge the links between letter-sound constituents and phonemic segments in the spoken word.

There is empirical evidence for a link between verbal STM and spelling. An early study by McLeod and Greenough (1980) examining sequencing ability in good and poor spellers reported that poor spellers have shorter verbal short-term memory spans than good spellers. This was true only for verbal and not for pictorial information. This finding mirrors similar research in reading which showed that children with reading problems had poorer short-term memory spans than good readers for verbal stimuli or visual stimuli that could be recoded phonologically (e.g. de Jong, 1998; Jorm, 1983; Rapala and Brady, 1990). This study did not show any differences in sequencing ability per se between good and poor spellers (see also Treiman, 1997, for discussion on this issue).

The studies by Ormrod (Ormrod, 1986; Ormrod and Cochran, 1988) appear to be the first published studies to have explicitly investigated associations between different components of working memory and spelling. Ormrod (1986) investigated the relationship between verbal STM and spelling ability in 10 matched pairs of students from the ninth and tenth grades (age approximately 14 and 15 years of age) who differed in spelling ability (good and poor spelling ability). The results showed that the good spellers performed significantly better than the poor spellers on simple span tests for digits and consonant letters. The study controlled for verbal ability. A possible confounding factor in this study was that the trials were conducted on a computer and familiarity with a keyboard might have affected the results. The study by Ormrod and Cochran (1988) examined verbal WM and spelling and involved forty-eight university undergraduates. Using a modified version of the Daneman and Carpenter (1980) working memory measure, the study found that verbal working memory accounted for a significant amount of additional variance in spelling after all measures of reading and verbal ability were taken into account. However, it is not possible to quantify the amount of variance from the data reported.

The above studies provide some evidence of relationships between verbal short-term and working memory and spelling ability over a wide age-range. To the writer's knowledge, there has been no subsequent research published that has examined working memory as a single factor in relation to spelling abilities, although the study by Cormier and Dea (1997) could be considered to have done so due to the methodological design, as will be discussed later. Most of the studies where spelling has been assessed (e.g. Cormier and Dea, 1997; Cornwall, 1992; McCallum et al., 2006; Pennington et al.; Savage and Frederickson, 2006; Savage et al., 2005; Scarborough, 1988; Tijms, 2004), have tended to follow the research paradigm described earlier for reading, namely, an exploration of the extent to which various factors including working memory contribute independently to the development of spelling skills. The majority of these studies have provided support for an association between working memory and spelling. However, many of the research findings are difficult to interpret for several reasons.

Two studies have reported a contribution to the variance in spelling by verbal memory measures (e.g. Cormier and Dea, 1997; Tijms, 2004). The study by Tijms (2004) involving Dutch children aged between 10 and 14 years of age reported that a verbal memory factor added 2% of unique variance to spelling over and above phonological awareness. However, verbal memory was assessed using a composite measure which included not only a short-term and complex verbal working memory task but also a list-learning task. Therefore, no conclusions can be drawn about the specific factors that may have contributed to the results. There is also the issue of the degree of transparency of the Dutch language in comparison with English, as discussed earlier.

With reference to the list-learning task used to assess verbal memory in the above study, such tasks are not typical measures of working memory. However, studies have used them for this purpose. For example, the study by Cornwall (1992) also used a list-learning task, the Verbal Selective Reminding Test (Buschke, 1973), to assess the relationship between working memory and spelling. TheVSRT, although it does rely on verbal memory, is principally designed to measure verbal learning (see Hannay and Levin, 1985). Cornwall reported no independent effect of verbal memory on spelling.

Table 2. Selected findings from studies showing the contributions of working memory and other cognitive variables to word reading and spelling

Study / Design	Sample	Independent Cognitive Variables and Tasks Used			Results		Comments
		Memory	PA	RAN	Word Spelling	Word Reading	
Cormier & Dea, 1997 (Canada) Cross-sectional correlational design	Typically developing children 36 grade 1 M = 6yrs10mths 32 grade 2 M + 7yrs 10mths 35 grade 3 M= 8yrs 11mths Total 103	**VSTM** Digit span forward **VWM** Digit span backward (both from Wechsler, 1974 **Visuo/Spat STM** Corsi Blocks forward **Visuo/Spat WM** Corsi Blocks backwards (Milner, 1971)	Test of Auditory Analysis (Rosner and Simon, 1971)	Not assessed in this study	**VM block** added sig. variance (4.6%) **Visuo/Spat memory NS** **PA added 6.4%** variance	**VM block added** sig. variance (4.7%) **Visuo/Spat memory NS** **PA added 9.6%** variance	ST and WM measures were combined. This study also examined working memory **before** phonological awareness measures were added to the regression equation.
Cornwall, 1992 (Canada) **Correlational**	54 children with specific reading difficulties M age 9 yrs 7 mth	**VWM** Sentence memory (Knights & Norwood, 1980) Verbal Selective Reminding test (Buschke, 1973) STM was not assessed	Rosner Auditory Analysis Test (Rosner & Simon, 1971	RAN Test for letters (Denckla & Rudel, 1976)	**VWM = both measures NS** **PA added 32%.** **RAN = NS**	**VWM** = Verbal Selective Reminding added 23%. **PA = NS** **RAN added 31%**	ST verbal memory not included. The Verbal Selective Reminding test is not a typical WM test . In contrast to other findings, PA did not have any independent effect on reading

Table 2. Selected findings from studies showing the contributions of working memory and other cognitive variables to word reading and spelling

Study / Design	Sample	Independent Cognitive Variables and Tasks Used			Results		Comments
		Memory	PA	RAN	Word Spelling	Word Reading	
McCallum, Bell, Wood, Below, Choate and McCane, 2006 (US) Correlational cross-sectional study	143 students with a range of specific learning difficulties 5 -13 years old M = 9 years	**STM** Letter memory (auditory) **WM** Letter memory (visual) (Both from TOD: Bell et al., 2003) **ST/WM** Entered as a block in the analysis.	Word manipulation (from TOD: Bell et al., 2003.) **+ Orthography:** Choosing correctly spelled word from choice of four (timed) (from TOD: Bell et al., 2003) **PA/ RAN/ Orthography** Entered in one block in the analysis - called phonological processing block.	Letters and numbers (from TOD: Bell et al., 2003).	**ST/WM Block = NS** (2.3%) **Phonological processing block** 16.3%.	**ST/WM Block = NS** (1.2%) **Phonological processing block =** 12.1 %.	Memory variables correlated modestly with word reading and spelling Not clear what the letter-visual test measuring Also only combined effect of memory variables and PA/RAN/Orth. Investigated.
Pennington et al., 2001 (US) Correlational cross-sectional study Results of regression analysis reported here	71 children aged 7.0 –18.0 years, with specific reading difficulties Matched with RA and CA controls (97) Total = 168	**STM** Word spans for real words, nonwords and rhyming words Composite score created	Phoneme reversal and pg Latin tasks Composite score created	Composite score from a range of lexical retrieval tasks	**STM** This was not included in the regression analysis PA = 11.8% ind. var. RAN = NS	**STM** This was not included in the regression analysis. PA = 6.1% ind. var. RAN = 2.4% ind. var.	Study investigated effects of a range of independent variables (e.g. articulatory speed, speech perception) on range of dep. variables

Table 2. Selected findings from studies showing the contributions of working memory and other cognitive variables to word reading and spelling

Study / Design	Sample	Independent Cognitive Variables and Tasks Used			Results		Comments
		Memory	PA	RAN	Word Spelling	Word Reading	
Pennington et al., 2001 (cont)							Modest ind. effects of RAN and STM reported across average and poor readers & spellers
Savage & Frederickson, 2006 (UK) Correlational	67 children with average to below average rdg and splg skills. Divided into 1. average 2. below-ave groups for both rdg and splg M age = 10.7	**STM** Digit forwards (BAS-II: Elliott et al, 1996). **WM** Digit backwards (BAS-II: Elliott et al., 1996	Nonword Decoding (PHAB; Frederickson et al., 1997).	Digit and Picture Naming Speed (Phonological Assessment Battery; Frederickson et al., 1997)	**STM / WM** both NS **PA** Nonwords: 1 > 2. (ES = 1.27). Rhyme: 1 > 2. (ES = 0.61). **RAN** Digits: 1 > 2. (ES = 1.32). Pictures 1 = 2.	**STM / WM** both NS **PA** Nonwords: 1 > 2. (ES = 1.27). Rhyme: 1 > 2. (ES = 0.71). **RAN** Digits: 1 > 2. (ES = 0.76). Pictures 1 = 2.	No reliable differences were found between average and poor readers or spellers on either the STM task or the WM task

Table 2. Selected findings from studies showing the contributions of working memory and other cognitive variables to word reading and spelling

Study / Design	Sample	Independent Cognitive Variables and Tasks Used			Results		Comments
		Memory	PA	RAN	Word Spelling	Word Reading	
Savage, Frederickson, Goodwin, Patni, Smith & Tuersley, 2005 (UK) Correlational *1. Discriminant Function Analysis* *2. Hierarchical Regression Analysis*	61 typically reading and spelling children 30 Grade 3 (between 7 yrs 5 mth and 8yrs 4 mth) 31 Grade 4 (between 9 yrs 5 mth and 10 yrs 4 mth).	STM Word List (WMTBC, Pickering & Gathercole, 2001) WM Digit backwards (BAS-II: Elliott et al., 1996	Spoonerisms Test and Nonword Reading Test (Phonological Assessment Battery; Frederickson et al., 1997)	Digit Naming Speed (Phonological Assessment Battery; Frederickson et al., 1997)	***Analysis 1*** ***VSTM*** discriminated between BA / A spellers but not between A / AA spellers WM not sig. PA discriminated between both groups RAN discriminated between BA / A spellers ***Analysis 2*** VSTM and WM NS *PA: Spoonerisms (26%)* *RAN (6%).*	***Analysis 1*** VSTM and WM not sig. PA discriminated between both groups RAN discriminated between BA / A readers ***Analysis 2*** VSTM and WM NS PA: Spoonerisms *(55%)* *Nonword (5%)* *RAN was NS*	Overall, PA was the best predictor variable for both reading and spelling RAN predicted below average reading and spelling VSTM predicted below average spelling but not reading Overall, neither RAN nor VSTM/WM were unique predictors of reading RAN added additional variance to spelling but not to reading

Table 2. Selected findings from studies showing the contributions of working memory and other cognitive variables to word reading and spelling

Study / Design	Sample	Independent Cognitive Variables and Tasks Used			Results		Comments
		Memory	PA	RAN	Word Spelling	Word Reading	
Scarborough, 1998 (US) Longitudinal	Children tested at Grade 2 (8yrs) and Grade 8 (14yrs) Complete data for 55 children Two subgroups: Poor readers (n = 19) Good readers (n = 36)	A nonword repetition task	Phoneme deletion tasks Real words at Grade 2 Pseudowords at Grade 8 adpated from Bruck (1992)	Grade 2 – picture naming Grade 8 – object and colour naming (Denckla and Rudell, 1976)	*Poor readers* STM was NS (r = .26) PA sig. (r = .38) RAN sig.(r = .64) Best predictor *Good readers* Best predictors of spelling were literacy scores at grade 2	*Poor readers* STM was NS. (r = .25) PA NS (r = .24) RAN sig.(r = .62) Best predictor *Good readers* Best predictors of reading were literacy scores at grade 2	Pearson correlations quoted -from regression analysis A range of rdg-related skills were examined PA, RAN and STM all associated with rdg and spllg at both grade levels For poor readers, RAN consistently the best predictor for the rdg- related skills, PA best predictor for spllg.
Tijms (2004). (Dutch) Correlational	267 children with specific reading difficulties Age 10-14	A memory factor comprising tasks taping into verbal STM (WISC-RN: Van Haasen et al., 1985), WM (Schaap, 1984)and list learning (Schaap, 1987)	A phonological factor comprising phoneme synthesis and auditory closure (from TVK: Van Bon, 1982)	Not assessed	ST/WM factor sig = 2% PA factor = NS	ST/WM factor sig = 4% PA factor = NS	Suggestion that the lack of effect of PA may partly be due to the more consistent orthography of Dutch vs. English

The second study which reported that verbal memory contributed to the variance in spelling was by Cormier and Dea (1997). This involved 103 typically developing children aged between 6 and 9 years of age. The study reported a significant contribution to spelling of 4.6% of the variance from verbal memory measures. This was without controlling for phonological awareness. When phonological awareness was included in the analysis it accounted for an additional 6.4% of the variance in spelling over and above the contribution of working memory. However, no analysis was reported to show if working memory added any additional variance to spelling after controlling for phonological awareness.

This study does provide evidence that verbal memory is a predictor of spelling. Unfortunately, the verbal memory measure used was a composite of a short-term and working memory measure and therefore it is not possible to separate out any component-specific contribution of verbal memory. Non-verbal measures did not contribute to the variance in either spelling or reading in this study.

The majority of studies which have controlled for phonological awareness have generally failed to find any independent effects of verbal memory on spelling production (e.g. Cornwall, 1992; McCallum et al., 2006; Pennington et al., 2001; Savage and Frederickson, 2006; Savage et al., 2005) although modest correlations between verbal memory measures and spelling have been reported (e.g. Cornwall, 1992; McCallum et al., 2006; Savage et al., 2005; Scarborough, 1998). However, the study by Savage et al. (2005) did find a unique effect of verbal short-term memory on spelling for poor spellers. This study explored the relationships between a number of cognitive factors in children of different levels of spelling ability. The study found that verbal ST and WM tasks loaded as a separate factor from both RAN and phonological awareness, suggesting that the memory tasks were tapping into a different underlying ability. A second analysis showed that verbal short-term memory but not working memory added unique power to the discrimination of below-average and average spellers beyond the contribution of RAN and phonological awareness. However, it did not discriminate between average- and above-average spellers or between either groups of readers. These findings have not been reported in other studies and they suggest that verbal short-term memory may be a unique predictor of below-average but not average or above average spelling. A hierarchical regression analysis provided further support for the specificity of the contribution of verbal short-term memory where this was found to add no additional variance to spelling across the whole sample once the effects of phonological awareness and RAN were taken into account. However, it is worth noting that in this regression analysis, verbal working memory contributed a modest although non-significant additional effect of 2% of variance across the whole group (Savage, personal communication, 13.06.08).

It is likely that the equivocal findings reported in studies to date reflect in part the same issues that arise in the interpretation of findings from the research into working memory and reading. One issue concerns the interrelatedness of various aspects of phonological processing, in particular, phonological awareness and verbal memory (e.g. Elbro, 1996; Muter, 2004; Muter and Snowling, 1998; Wagner and Torgesen, 1987). This makes it difficult to identify the extent to which each might distinctively influence the development of literacy skills.

The choice of measurement tasks used could also affect results. For example, it is acknowledged that phonological awareness tasks necessarily make demands on working memory (Bradley and Bryant, 1985). This makes it difficult to separate out any contribution of working memory or phonological awareness to an effect, but also that different tasks make different demands on both ST and WM depending on the complexity of the task (e.g. Oakhill and Kyle, 2000; Yopp, 1988). A factor analytic study by Yopp (1988) identified two distinct phonological awareness factors. Tasks which required only one operation for completion loaded onto the first factor, whereas those which loaded onto the second factor required more than one operation and thus, according to Yopp, made greater demands on memory. These results are supported by Oakhill and Kyle (2000) who reported that a complex verbal WM task predicted unique variance in performance above reading ability on a sound categorisation task but not on a phoneme deletion task.

Turning to verbal STM tasks, these may also differ in the extent to which they could be considered 'pure' measures of phonological loop function. Gathercole and colleagues (e.g. see Gathercole, 2006; Gathercole, Willis, Baddeley, and Emslie, 1994) argue that nonword recall is a purer measure of phonological loop capacity than the more traditional methods of verbal short-term memory such as digit span and word span. This is because nonwords are less easy to articulate than the more familiar digits or real words and therefore are less easy to refresh through active rehearsal (but see Snowling, Chiat and Hulme, 1991 for an alternative viewpoint). Taken together, these studies suggest that it is not only difficult to separate out any independent effects of phonological processes due to the closely interacting nature of these factors, but that results for dependent measures may additionally be task-dependent (e.g. see Georgiou, Das and Hayward, 2008: also Friedman and Miyake, 2005; Chapter 4 for further discussion on measurement-related issues).

A second factor which makes it difficult to interpret the results from research is that there is evidence to suggest that, at least in relation to reading, different phonological skills change in their degree of importance as children's literacy skills develop (e.g., Gathercole, Willis, Emslie, Baddeley, 1991; Scarborough, 1998; Rohl and Pratt, 1995; Torgesen et al., 1997). There is also evidence from studies reporting correlations between working memory measures and phonological awareness that these abilities may diverge as children's literacy skills develop (e.g. see Rohl and Pratt, 1995; Savage at al., 2005). The underlying reasons for such findings are not clear, but it may be partly a result of a bidirectional relationship between phonological processing and literacy skills (e.g. Perfetti et al., 1987; Wagner et al., 1994).

Visuospatial memory

A generally consistent finding from the working memory and reading research has been that visuospatial memory is not associated with the development of reading skills (e.g. Liberman, Mann, Shankweiler and Werfelman,1982; Rapala and Brady, 1990; for reviews see Frost, 1998; Vellutino et al., 2004). Only one study (Cormier and Dea, 1997) has been located by the author which explored the contribution of non-verbal memory to spelling. This study found no evidence of a significant contribution of non-verbal memory to either spelling or reading achievement, lending further support to the studies into reading. The study by McLeod and Greenough (1980) also provided some evidence of a lack of association between spelling and non-verbal ST memory.

It might be expected that children's visual/spatial memory would be important for spelling, as when writing down the spellings of words children have to produce letters accurately and in sequence. Goswami (2002) also notes that spellings are often checked by writing down the alternative possibilities to see which one "looks right" (p. 967) and there is some experimental evidence to suggest that visually inspecting a spelling is helpful in making correct spelling decisions (Tenney, 1980). Visual memory for orthographic images has also been shown to be important for proficient spelling (e.g. Ehri, 1980) as it helps children to build up a memory bank of correct spelling patterns. However, there is no evidence to suggest that visual/spatial memory *per se* is an important underlying cognitive factor in spelling or reading development. In contrast, there is some evidence to suggest that children who continue to read using mainly visual strategies are typically very poor spellers and also encounter serious reading difficulties after a certain stage (Bradley and Bryant, 1980; see also Frith, 1980; Palmer, 2000b).

Previous research has suggested that children with literacy difficulties may place a much greater reliance on visual and orthographic coding in memory than on phonological coding when reading and spelling (e.g. Hulme, 1981; Lennox and

Siegel, 1998; Rack, 1985) although the precise meanings of the terms visual and orthographic coding in relation to words is underspecified in the literature. The study by Stuart, Masterson and Dixon (2000) looking at young children's ability to acquire a sight-word vocabulary found that there was a significant correlation (r = 0.8) between the visual memory scores of children who had poor graphophonic skills and their sight-word learning. In contrast, for children with good graphophonic skills there was no association between word-learning and visual memory. Graphophonic skills are defined as the ability to segment words into sounds and knowledge of letter-sound mappings.

It seems reasonable to expect that if children's phonological skills are compromised then they may draw on other cognitive components to support their learning, such as their visual memory. It has been shown, however, that this is not the optimal strategy for the development of effective literacy skills, at least for reading. In the study by Stuart et al. (2000), the group of children with good graphophonic skills showed better learning throughout the training period and better retention than those with poor graphophonic skills. However, the two groups of children did not differ significantly in their visual memory scores reinforcing the view that visual memory is the 'strategy of last resort' for those who have no other available (p. 18).

Examining this issue from a working memory perspective, it has been shown that all measures of working memory components show a steady increase from pre-school through to adolescence (e.g. Case, Kurland and Goldberg, 1982; Gathercole, Pickering, Ambridge and Wearing, 2004a). It has been suggested that part of this increase might be attributable to a developmental shift towards the use of phonological recoding of pictorial information. A number of studies have shown that children over the age of seven years of age begin to recode visual material where possible into a phonological form for immediate storage, whilst children under seven tend to rely mainly on a visual strategy (e.g. Hitch et al., 1988, 1989b, 1991; Hitch, Woodin and Baker, 1989a).

As already discussed, children with literacy difficulties make inefficient use of phonological codes in working memory, leading to reduced working memory capacity (e.g. Brady, 1997; Goswami, 2002) However, Palmer (2000b) has suggested that for children with literacy difficulties, phonological recoding of visual material such as the print on a page is not just a matter of accessing the phonological representation of the visual material but also the ability to inhibit visual encoding which might cause interference. This requires the involvement of the central executive of working memory. If this ability to inhibit is impaired then visual and phonological stimuli compete for resources thus leading to a reduced storage capacity. Palmer's (2000b) study investigated phonological recoding in working memory in children between the ages of 5 and 8 years old. The study reported that the ability to access phonological representations of visual material accounted for up to 18% of the variance on a single-word reading test. However, from the age of 7 years and above, the capacity to inhibit the visual response also accounts for an additional 10% of unique variance. The study also showed that children over the age of seven years of age who still relied on visual strategies in working memory had significantly lower attainment levels in both spelling and reading levels. In effect, Palmer is suggesting that dual-coding, whilst it has been shown to be advantageous in adult memory (Paivio,1969), may actually have the opposite effect in children in that paying attention to more than one type of representation might take up too much of the limited cognitive resources in working memory thus leaving fewer resources for other processes such as phoneme blending.

This above theory is controversial and as yet has been relatively unexplored the literature. Savage et al. (2007) argue that clear evidence of competition between verbal and visual processing has not been demonstrated by Palmer, and that use of a visual strategy by children could equally reflect a response to (namely, compensation for) a basic problem in phonological processing. Savage et al. further argue that more research is needed including longitudinal studies of children using distinct patterns of single and dual coding from early in their school careers. In addition, it would be necessary to provide evidence to show that dual coding problems in WM as

Palmer suggests are distinct and additional problems to those of rapid naming or phonological processing to provide evidence of their unique role.

As a final comment on this issue, it is important to note that in their developmental studies of phonological recoding strategies in children, Hitch and colleagues do not suggest that phonological recoding of visual material replaces visual coding. Rather, the researchers emphasise that as children become older they are able to utilise both forms of coding as well as possibly other forms to support memory, although phonological coding is thought to predominate (e.g. Hitch et al., 1989a, b).

Summary

Overall, no definite conclusions can be drawn from the existing research regarding the relative importance of different working memory components in learning to spell, particularly with respect to their importance in comparison with other phonological processing variables. However, most of the studies reviewed have identified moderate relationships between verbal memory and spelling. Some have reported unique effects of verbal STM (e.g. Savage et al., 2005) and composite verbal memory factors on spelling (e.g. Cormier and Dea, 1997; Tijms, 2004). There is no evidence of an association between non-verbal memory and spelling (Cormier and Dea, 1997; McLeod and Greenough, 1980).

It is likely that the issues relating to the interpretation of results from the research into working memory and spelling are similar to those for reading. As yet, we do not know the extent to which verbal short-term or working memory may be important predictors of spelling independently of other phonological variables due to the closely interactive nature of these processes. However, given the lack of studies that have investigated links between working memory and spelling, more research is required before any conclusions can be drawn.

2.3 GENERAL SUMMARY AND CONCLUSIONS

Variation in phonological abilities is thought to be a primary cause of children's difficulties with spelling. Three phonological processes have been of greatest interest to researchers. These are phonological awareness, phonological coding in working memory, and phonological retrieval. A key issue which has been explored is the extent to which each of these processes can be considered to be a distinct factor underlying spelling and reading development or if they may be better understood within a single broad phonological core factor. As yet there are no clear answers to these questions, particularly with respect to spelling.

Spelling has been a relatively neglected area of research in comparison with reading. However, the evidence that is available suggests that all of the three major phonological processes identified in the literature (e.g. Wagner and Torgesen, 1987) are important underlying factors in spelling. Both phonological awareness and RAN measures have been shown to account for significant additional variance in spelling performance, with phonological awareness being the strongest predictor of spelling. Working memory has also been shown to predict spelling performance but generally not when other phonological factors have been taken into account. However, working memory, particularly verbal memory, still has a significant role to play in spelling.

Overall, the existing evidence suggests that the same phonological processes are important for both spelling and reading. However, the patterns of association between these processes and reading and spelling may show some variations. For example, there is evidence to suggest that phonological awareness, particularly through interaction with letter knowledge, may be more important for early spelling than for early reading. It has also been suggested that there may be some quite specific RAN-spelling associations reflecting the ability to access phonological codes for orthographic information. Finally, there is some evidence to suggest that verbal short-term memory may be more important to spelling for poor readers and spellers than for good readers and spellers, although verbal working memory has been shown to contribute albeit modestly. However, all of these conclusions are based on a relatively small number of studies and more research is needed, particularly in relation to the role of working memory and spelling as well as the specificity of RAN-spelling associations. Research linking the dual-route model of spelling and working memory may be helpful in identifying whether working memory components are differentially involved in spelling depending on whether a phonological or a lexical route is accessed. Research is also needed into the possibility of a dual-coding conflict in the working memory system between visual and phonological information in children with literacy difficulties.

The next chapter will explore the working memory system in some detail. It will look specifically at how different components of working memory handle information gathered through different sensory modalities by examining the Baddeley and Hitch multicomponent model of working memory. However, other models of working memory will also be considered as well as issues relating to the development of working memory and how working memory may be measured.

CHAPTER 3. WORKING MEMORY

Within the last three decades working memory has become one of the most influential theoretical constructs in the study of human cognition. Working memory (WM) has been described as a limited-capacity and time-limited active memory system that has the ability to store and simultaneously process information (Bayliss, Jarrold, Baddeley, Gunn, and Leigh, 2005). There is now a considerable body of literature linking working memory with a range of abilities and attainments. For example, it has been shown to be associated with measures of general ability (e.g. Engle, Tuholski, Laughlin and Conway, 1999b), verbal and non-verbal reasoning skills (Kyllonen and Christal, 1990), and measures of academic ability in a range of areas such as reading (e.g. De Jong, 1998; Gathercole et al., 2006; Swanson and Jerman, 2007), spelling (Ormrod and Cochran, 1988), reading comprehension (e.g. Daneman and Carpenter, 1980; Cain, Oakhill and Bryant, 2004), and mathematics (e.g. Bull and Scerif, 2001; DeStefano and LeFevre, 2004; Gathercole et al., 2006). Working memory span scores have also been shown to be strongly associated with children's general abilities at school entry at 4 years of age, as rated by teachers (Alloway, Gathercole, Adams, and Willis, 2005) and with attainments in national curriculum assessments in English, mathematics, and science in England (e.g. Gathercole, Brown, and Pickering, 2003; Gathercole and Pickering, 2000a; Gathercole, Pickering, Knight, and Stegmann, 2004b; Jarvis and Gathercole, 2003).

Knowledge and theories of working memory have developed to such an extent that it would be beyond the scope of this study to present even an overview of these theories (see Miyake and Shah, 1999, for a systematic comparison of some major theories of working memory). Instead, this chapter will be restricted to a summary of the main cognitive, conceptual perspectives on working memory illustrating some of the most significant models and theories, with an expanded discussion of the multicomponent model of working memory first developed by Baddeley and Hitch (1974) and later elaborated by Baddeley and his colleagues (Baddeley, 1986, 2000;

Baddeley and Hitch, 1994; Baddeley and Logie, 1999). This will be followed by a review of the methods by which working memory is assessed with a discussion of some of the measurement challenges facing researchers. Finally, the structural organisation and development of working memory in children will be reviewed. The chapter will conclude with a summary of the key points discussed.

3.1 MODELS OF WORKING MEMORY

Working memory as a concept arose out of the view advocated in the early 1960s of a distinction between two main memory systems, a relatively stable system of long-term memory and a more fragile and temporary system which has been variously described as primary memory or short-term memory (see Baddeley, 1997, for a historical overview of the development of the working memory concept). As stated earlier in Chapter 2, the term working memory is generally used in cognitive psychology to describe an active memory system that is responsible for the temporary storage and simultaneous manipulation of information (Bayliss et al., 2005).

There are several significant theoretical perspectives on working memory. Some of these perspectives emphasise distinctions between processing and storage (e.g. Barrouillet and Camos, 2001; Case et al., 1982; Daneman and Carpenter, 1980; Engle, Cantor and Carullo, 1992; Just and Carpenter, 1992; Towse and Hitch, 1995). Others emphasise controlled attention and activation of long-term memory (e.g. Engle, Kane, and Tuholski, 1999a; Cowan, 2005) or *long-term working memory* (Ericsson and Kintsch, 1995). Other models focus on the types of structures involved in working memory processes (e.g. Baddeley, 1986, 2000; Baddeley and Hitch, 1994; Baddeley and Logie, 1999). However, it should be noted that these distinctions are not always clear-cut and there are many areas of overlap among these differing perspectives.

3.1.1 Models emphasising processing and storage

The distinction between processing and storage has generated a number of alternative viewpoints regarding the factors that constrain the capacity of working memory. For example, *resource-sharing* models propose that there is a flexible but limited pool of resources that can be utilised for either storage or processing. The result is a trade-off between processing and storage demands (e.g. Case et al., 1982; Daneman and Carpenter, 1980; Engle et al., 1992; Just and Carpenter, 1992). In the influential study by Case et al. (1982) which examined counting speed in children and adults, it was found that there was a linear relationship between memory capacity and processing speed in children aged between 6 and 12 years of age, with older children counting more quickly and obtaining higher counting spans. Case et al. argued that the increases in performance (as measured by counting span) were due to increases in operational efficiency as basic processing operations became faster and more efficient. This resulted in more resources becoming available for storage.

Similar interpretations based on a trade-off of resources, with resources sometimes depicted as activation energy, have been used to explain adult performance on a range of working memory span tasks involving other operations (e.g. Engle et al., 1992; Just and Carpenter, 1992). However, the trade-off hypothesis has been challenged by some researchers. For example, Towse and Hitch (1995) argue that working memory limitations arise from the fact that individuals are not able to process and store information at the same time. This means they must continually switch back and forth between storage and processing. The researchers suggest that the higher counting span of the older children found in the study by Case et al. (1982) could have arisen because the older children could count more quickly. This would have had the effect of decreasing the time that information was held in storage, resulting in less information being lost through the process of decay. Towse and colleagues have put forward a *task-switching* account of working memory which proposes that memory representations in storage decay when attention is diverted to processing (see also Hitch, Towse, and Hutton, 2001). Evidence consistent with this task-switching model was provided in a series of studies that either varied counting complexity while holding retention interval constant (Towse and Hitch, 1995) or manipulated retention requirements in counting, operation, and reading span tasks while holding the overall processing difficulty constant (Towse, Hitch, and Hutton, 1998; see also Conlin, Gathercole, and Adams, 2005).

Another view which has been proposed is that of Barrouillet and colleagues (Barrouillet and Camos, 2001; Barrouillet, Bernardin and Camos, 2004;; Barrouillet, Bernardin, Portrat, Vergauwe, and Camos, 2007; Portrat, Camos, and Barrouillet, 2009). These researchers argue that it is not the total length of time taken up by processing *per se* that determines the amount of material that is forgotten, but the extent to which the processing element of the task being undertaken prevents individuals from switching their attention to the maintenance of material held in storage. Their *Time-Based Resource-Sharing (TBRS)* model (Barrouillet et al., 2004, 2007) proposes that the capacity of working memory depends on the cognitive load of a task. This in turn is a function of the proportion of time during which the task captures attention. Tasks with a high cognitive load are those that demand continual attention, thus preventing the switch between storage and processing. In contrast, tasks which have a low cognitive load allow more frequent switching of attention, thus enabling the memory representations in storage to be refreshed.

3.1.2 Working memory as control of attention

Most current theories of working memory view attentional processes as being central to explanations of the mechanisms involved in carrying out tasks with a cognitive dimension. Kane, Engle and colleagues (e.g. Engle, 2002; Kane, Bleckley, Conway, and Engle, 2001) propose that the ability to control attention is central to working memory. The control of attention is described as "an executive control capability; that is, an ability to effectively maintain stimulus, goal, or context information in an active, easily accessible state in the face of interference, to effectively inhibit goal-irrelevant stimuli or responses, or both" (Kane et al., 2001, p.180). Evidence for this model comes from studies which show that participants with a high memory span are more able to control and resist interference than participants with a low memory span (Kane et al, 2001).This then allows them to retain and process more information. This view of working memory suggests that individuals with a high working memory span may not necessarily have a greater short-term storage capacity than those with a low span, but rather that working memory capacity is constrained by the executive capacity to control attention and resist interference (see also Hester and Garavan, 2005). Kane and Engle also emphasise the role of working memory in retrieving and actively maintaining information from long-term memory (Kane and Engle, 2000).

Cowan's model of working memory also emphasises attention control as well as links with long-term memory (e.g. Cowan, 1999, 2001, 2005). His model proposes that essentially working memory refers to information in long-term memory that is activated above some threshold by a process of attention. His model proposes the 'focus of attention', which is capacity limited and is integrated with attention operations. Cowan describes working memory as being divided hierarchically into three levels that differ in the accessibility of the information held. The levels relate to (a) highly active elements that are within the focus of attention, (b) a set of elements that are activated above a certain threshold but are outside the focus of attention, (c) inactive elements of memory with sufficiently pertinent retrieval cues. All information that is within conscious awareness occupies the focus of attention. The second level contains information that is activated but not to the point of conscious awareness. However, through conscious processing, items in the activated pool can quickly move in and out of the focus of attention depending on what is needed at the time. Finally, information that is not in an activated state can also be considered to be in working memory if there are cues in working memory that raise the possibility that it could be retrieved if necessary (Cowan, 1999). Cowan also proposed that the focus of attention includes new information as well as activated information from LTM. New links formed between the various elements comprise an episodic record that will become part of LTM (Cowan, 1995; Cowan and Chen, 2009). The ability to deploy attentional resources is an essential feature of Cowan's model. The capacity limitation of working memory arises due to the limited capacity of the focus of attention.

Cowan's research on working memory has been extremely influential in expanding the construct of working memory and working memory capacity (e.g. Cowan, 2005). Following a comprehensive review of the literature on working memory capacity, Cowan re-evaluated the evidence on working memory capacity and concluded that the limit was closer to four than seven (Miller, 1956). The figure of four indicated the number of 'chunks' of information that could be held at one time in the focus of attention (Cowan, 2001). A chunk is defined as a memorable group of items that results from pairing or combining discrete pieces of information, such as creating a set from two or three adjacent words (Dehn, 2008). Cowan also suggests that this number of four is almost universal and applies across individuals, modalities and levels of expertise (Cowan, 2005). However, not all researchers agree. For example, Oberauer (2002) suggests that working memory can process only one chunk of information at any one time. Gobet and Clarkson (2004) contend that the real number may be closer to two, and that the capacity of short-term and working memory is really less than we thought, or that we have been overestimating the size of chunks (see also review by Verhaeghen, Cerella and Black, 2004).

3.1.3 Long-term Working Memory

The concept of working memory as activated long-term memory is more dominant in the working memory model of Ericsson, Kintsch and colleagues (Ericsson and Kintsch, 1995; Ericsson and Delaney, 1999; Ericsson, Patel, and Kintsch, 2000). Essentially, their theory describes working memory as the skilful utilization of information that is stored in long-term memory. Ericsson and his colleagues argue that traditional views of working memory capacity cannot explain an individual's ability to carry out a complex task, such as language comprehension. As evidence they cite the fact that adults are able to precisely recall meaningful sentences of twenty or more words after only a brief presentation (Ericsson and Chase, 1982).

However, if the words in the sentence are randomly re-arranged then accurate recall drops to around six words. The superior performance when recalling meaningful sentences is attributed to the ability not only to chunk and store information in LTM, but also to line these chunks together through retrieval structures. Cues to retrieval come from information in short-term memory which can be rapidly integrated within these retrieval structures to access relevant chunks of information.

Ericsson and his colleagues have carried out a body of research examining the performance of memory experts and chess masters. Their work has suggested that the skilful use of information held in long-term memory appears to depend on the use of mnemonics, and that individuals can be trained to dramatically increase their immediate recall of digits from around 6 to over 80 through the employment of a practiced mnemonic (Ericsson and Chase, 1982). The researchers argue that by using such strategies, individuals can quickly encode incoming information into LTM while attaching retrieval cues that are maintained in short-term memory. However, the researchers also emphasise that the critical feature of expert memory that allows the expert to perform a task, such as selecting moves in chess, is not just the amount that can be recalled but also the ability to rapidly extract and store important patterns and relevant information (Ericsson et al., 2000).

3.1.4 The Multicomponent Model of Baddeley and Hitch

The multi-component model of working memory first developed by Baddeley and Hitch (1974) and later elaborated by Baddeley and his colleagues (Baddeley, 1986, 1996a, 2000; Baddeley and Hitch, 1974; Baddeley and Logie, 1999) is one of the most well-developed and empirically validated models of working memory. This model was proposed to replace the previous conceptions of short-term memory which viewed STM as a unitary temporary storage system, an approach which was typified by the model of Atkinson and Shiffrin (1968).

The Baddeley and Hitch model emphasises separate subsystems of working memory as well as executive, attention-demanding processes. It describes four separate but interrelated components: the central executive, the phonological loop, the visuospatial sketchpad, and a more recently added component called the episodic buffer (see Figure 2).

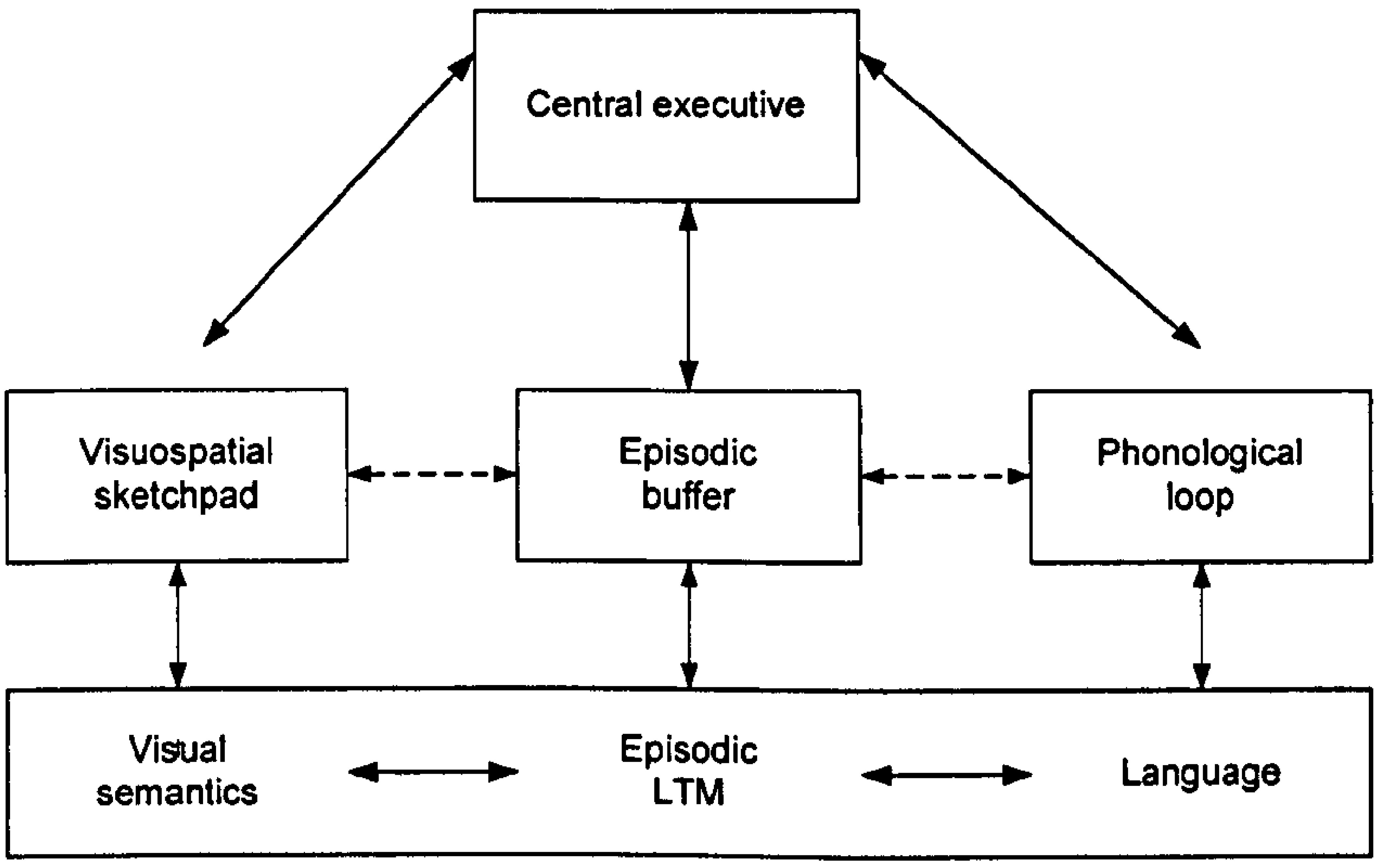

Figure 2. The revised multicomponent model of working memory (adapted from Baddeley, 2007). The shaded area represents crystallised or long-term memory systems.

The central executive is held to be responsible for the control and regulation of the whole working memory system. The phonological loop and the visuospatial sketchpad are two systems specialised for the storage and manipulation of material from different informational domains. The phonological store holds information in a phonological code. The visuospatial sketchpad is said to be specialised for short-term storage and manipulation of visuospatial information (Baddeley and Hitch, 1974). The newest component, the episodic buffer, has more recently been fractionated from the central executive; this is described as a multidimensional representation system capable of integrating temporary representations from other cognitive systems including components of working memory (Baddeley, 2000). The theoretical specification of each of these components is said to be undergoing continuous revision in the light of new research and the need for more detailed specification to account for new data (Baddeley, 2007). For example, initially links between the buffer and the two subsystems were thought to operate via the central executive. However, new research suggests that there may be also be direct links (Allen and Baddeley, 2009; Baddeley, 2007). These additional links are included in Figure 2.

Evidence for the Multicomponent Model

There is substantial amount of evidence for the basic modular structure of the Baddeley and Hitch (1974) working memory model. This evidence comes from both experimental and neuroimaging studies. Most of the experimental evidence comes from dual-task studies showing selective interference effects found in typically functioning adults. The dual-task methodology hinges on the idea that if two tasks can be performed simultaneously without producing a substantial drop in performance, these tasks can be assumed to be independent (Mohr and Linden, 2005). Dual-task studies have provided evidence for the separability of verbal and visuospatial informational domains (e.g., Farmer, Berman, and Fletcher, 1986; Logie, 1986; for review see Baddeley and Hitch, 1974) and the separability of the central executive from passive storage components (see Baddeley and Hitch, 1974, and Baddeley and Logie, 1999, for reviews). Within the domain of verbal memory, studies employing latent variable analysis to explore the relationships between verbal short-term and working memory tasks provide evidence of a distinction between verbal storage and processing (e.g. Conway, Cowan, Bunting, Therriault, and Minkoff, 2002; Engle et al., 1999b). However, there is growing evidence to suggest that within the visuospatial domain, a distinction between storage and processing is less clear. For example, studies have suggested that there may be a much stronger link between visuospatial STM and the central executive than between the phonological loop and the central executive (e.g. Gathercole and Pickering, 2000b; Miyake, Friedman, Rettinger, Shah, and Hegarty, 2001; Quinn and McConnell, 1996; Wilson, Scott, and Power, 1987) which is not accounted for by the current multicomponent model. Baddeley (1996b) has suggested that it may be that "many uses of visual imagery are somewhat less practiced or automatic than the phonological coding that occurs for verbal information, and consequently tasks using the sketchpad often seem to place heavier demands on the central executive" (Baddeley, 1996b, p. 13470; cited in Miyake et al., 2001: see also Baddeley, Cocchini, Della Sala, Logie, and Spinnler, 1999).

Evidence of the need for an additional component, the episodic buffer, comes from studies showing clear links between working memory and long-term memory (e.g. Baddeley and Levy, 1971; Baddeley, Vallar, and Wilson, 1987; Miller, 1956) and from studies suggesting some form of association between verbal and visual information (e.g. Logie, Della Sala, Wynn, and Baddeley, 2000). There is also the need to account for the more complex binding of information in conscious awareness (Baddeley, 2000; see also Baddeley and Andrade, 2000, for a discussion of the relationship between the working memory model and conscious awareness). The original tripartite model contained no mechanism by which this data could be explained.

Neurological evidence for the multicomponent structure of working memory comes from studies using brain-imaging and also neuropsychological studies of working memory. Such studies have been able to identify distinct regions of the brain associated with particular working memory components (see Henson, 2001; Osaka and Osaka, 2007; Vallar and Papagno, 2002, for reviews). For example, the retention of verbal information in the phonological loop has been shown to activate brain areas in the left hemisphere spanning inferior parietal areas (serving phonological storage) and more anterior temporal frontal areas (associated with rehearsal), including Broca's area and the premotor cortex (e.g. Henson, Burgess, and Frith, 2000; Smith and Jonides, 1997). Visuospatial information is said to be associated with right-hemisphere activation in occipital and inferior frontal areas (Smith and Jonides, 1997). Activities linked with the central executive are associated with a variety of regions within the frontal lobes and also some posterior, mainly parietal, areas (e.g. Collette and Van der Linden, 2002; D'Esposito et al., 1995; Owen, Evans, and

Petrides, 1996). Finally, evidence for the episodic buffer comes from recent studies showing that tasks which involved or required the integration of information in working memory resulted in greater activation within right prefrontal areas of the brain (Prabhakaran, Narayanan, Zhao and Gabrieli, 2000; Zhang et al., 20040).

The phonological loop

The phonological loop is assumed to be responsible for the storage and maintenance of information in a phonological form. It has been fractionated into two principal components: a passive storage component capable of holding information in a phonological code for very brief periods of time (i.e. seconds) and an articulatory rehearsal system which can be used either to maintain items through repetition or to register visually presented material within the store by a process of articulatory naming (Baddeley, 1986). The phonological store is supported by studies showing what is known as the *similarity effect*, which shows that immediate serial recall of items that are similar in sound is poorer than that of dissimilar sounding items (Conrad and Hull, 1964; Baddeley 1966; Wickelgren, 1969). The articulatory rehearsal system is supported by studies showing the *word length effect*, that is, the tendency for immediate serial memory span to decline with the number of syllables in the words to be remembered (Baddeley, Thomson, and Buchanan, 1975). The precise interpretation of this latter phenomenon remains open to debate (see Baddeley and Hitch, 2007) but is said to reflect both the longer time it takes to articulate the words at encoding (Baddeley et al. 1975) as well as at retrieval (e.g. Cowan et al., 1992) leading to loss of information through decay. Further support for the articulatory rehearsal system comes from studies which have shown that the process of articulatory suppression, where participants are asked to repeatedly articulate an unrelated word thus preventing the articulatory rehearsal process, causes the word-length effect to disappear (Baddeley, Lewis, and Vallar, 1984). Finally, studies have also consistently demonstrated that exposure to irrelevant speech but not white noise, either concurrent with or subsequent to presentation of list items, significantly reduces serial recall of verbal items (e.g. Colle and Welsh, 1976;

Salamé and Baddeley, 1990; Neath 2000). It is suggested that this effect is brought about by interference with the representation while it is being held in the phonological store, although again this issue remains open to debate (Baddeley and Hitch, 2007). However, an alternative view to account for the major effects observed when memory is tested by immediate serial recall is Nairne's Feature Model (Nairne, 1990; see also Neath and Surprenant, 2005). This model distinguishes between primary and secondary memory. The model has no capacity limits and proposes that all information is lost through interference and not through decay. According to the model, all information regardless of the task is recalled from secondary memory and is driven by cues in primary memory. The best match for each cue is selected as a potential response. However, if a cue has some of its features interfered with, for example, through similarity with another feature, then the probability of successful sampling is reduced. These issues remain an area of active continuing controversy.

Finally, it has been suggested that the phonological loop may have developed as a mechanism to facilitate the acquisition of language (see Baddeley, Gathercole, and Papagno, 1998 and Baddeley, 2003, for discussion). Evidence of this comes from studies that have shown that patients with a classical STM deficit show impaired ability to learn words from a foreign language but are unimpaired in their ability to learn non-associated word-pairs in their own language (e.g. Baddeley, Papagno, and Vallar, 1988). It also comes from studies of normal children for whom the capacity to hear and repeat back an unfamiliar pseudoword (nonword repetition) predicts levels of vocabulary development (Gathercole and Baddeley, 1989). Baddeley et al. (1998) suggest that the primary purpose for which the phonological loop evolved is to store unfamiliar sound patterns in order to facilitate the learning of new words.

The visuospatial sketchpad

This visuospatial sketchpad is assumed to form an interface between visual and spatial information, allowing a range of channels of visual information to be bound together with similar information of a motor, tactile, or haptic nature (Baddeley

2002). Logie (1995) has suggested a fractionation of the sketchpad into a passive visual storage component, termed the visual cache, and a dynamic spatial retrieval and rehearsal process, called the inner scribe. Evidence for this distinction comes from a number of converging sources (e.g. Della Sala et al., 1999; Hartley et al, 2001; Hecker and Mapperson, 1997; Klauer and Zhao, 2004; Logie and Pearson, 1997). For example, the study by Della Sala et al. (1999) demonstrated that a spatial interference task significantly disrupted performance on a test of spatial working memory but it had no effect on a test of visual working memory, while a visual interference task had the opposite effect. The study by Logie and Pearson (1997) suggested that memory for patterns in children was better than memory for sequences of movements, and that this difference became more pronounced with increasing age, suggesting that visual and spatial memory have distinct developmental pathways. The distinction between visual and spatial storage and maintenance is currently the most commonly accepted position. However, a number of different theoretical perspectives on the capacities and properties of the VSSP have also been proposed and this remains an active area of research (for further discussion see Pickering, 2001; Repovš and Baddeley, 2006).

The central executive

The central executive is acknowledged to be the most complex component of the multi-component working memory model and the one said to present the most difficult challenge (e.g. Baddeley, 1986, 1996a, 2007). The central executive component was underspecified in the original 1974 model. It has since been elaborated as a result of further research. However, as yet there are many issues relating to its functions that remain unresolved (e.g. Repovš and Baddeley, 2006)

The central executive has similarities to the model proposed by Engle and colleagues (e.g. Engle et al., 1999a) and Cowan's focus of attention (e.g. Cowan, 2005) in that it emphasises attentional control (e.g. Baddeley, 1986). Baddeley (1996a) adopted the supervisory activating system (SAS) of the Norman and Shallice (1986) model of attentional control as a framework for conceptualising the central executive. This model distinguishes between two systems. The *contention scheduling* system activates semi-automatic schemata to accomplish routine, everyday actions. The *supervisory attentional system* (SAS) is an attentionally demanding system used for modifying and controlling action when the habit-based systems needs to be overridden, such as when encountering novel or problematic situations. Currently, the executive functions which are thought to be central to attentionally demanding action and therefore under the control of the central executive include the capacity to divide attention (e.g. Logie, Cocchini, Della Sala, and Baddeley, 2004), the capacity to attend and inhibit in a selective manner (e.g. Baddeley, Emslie, Kolodny, and Duncan, 1998), and updating information in long-term memory (e.g. Baddeley, 1998: for reviews see Baddeley, 2007; Baddeley and Repovš, 2006).

Miyake et al., (2000) examined Baddeley's structure and identified three of the most frequently described executive functions: shifting of mental sets, monitoring and updating of working memory representations, and inhibition of prepotent responses. Factor analysis showed that these three functions were moderately correlated but clearly separable (see also Oberauer, Süß, Wilhelm and Wittmann, 2003). However, investigations exploring the core executive functions in working memory, indeed research into the whole area of executive functioning during the performance of complex cognitive tasks, is still ongoing (e.g. Alvarez and Emory, 2006; Kane and Engle, 2003; Salthouse, 2005) and there remains considerable controversy regarding the specific constructs that may be considered 'executive' (see Booth and Boyle, 2009, submitted; Monsell and Driver, 2000).

The episodic buffer

The episodic buffer is a multidimensional system which is capable of providing a link between the more specialised components of working memory and other cognitive systems. This component is a relatively recent addition to the model and is still under investigation, particularly with respect to how information from different sensory modalities is maintained and how it may be bound or integrated within working memory (e.g. Allen, Baddeley and Hitch, 2006; Cowan, Saults, and Morey, 2006; Rudner and Rönnberg, 2008: see also Allen and Baddeley, 2009; Baddeley, 2007; Repovš and Baddeley, 2006). Binding of information was initially postulated to require active central executive processing and consequently to be resource demanding. Therefore in the initial formulation of the episodic buffer (Baddeley, 2000) although the phonological loop and the visuospatial sketchpad had direct access to LTM, links between the two subsystems occurred via the central executive. However, later research showed that some aspects of binding such as the binding of words into meaningful sentences occurred relatively automatically, whilst the integration of unrelated sentences or the creation of novel connections between knowledge structures was more resource demanding (e.g. Jefferies, Lambon Ralph, and Baddeley, 2004). Studies in the visuospatial domain have also shown that the binding of visual / spatial features can also occur automatically (e.g. Allen et al., 2006; Luck and Vogel, 1997: see also Allen and Baddeley, 2009, for further discussion of studies on binding).

Currently, Baddeley and colleagues suggest a distinction between a set of relatively passive or automatic binding processes, and a more controlled, attention-demanding process of active binding, with the assumption that executive processes will be involved in active, but not automatic, binding. The type of binding which takes place within the episodic buffer is said to be likely to depend on a number of factors, such as the length of stimulus exposure, the type of associations required, and, or as well as, the stimulus complexity (Allen et al., 2006).

3.2 THE OPERATIONALISATION OF WORKING MEMORY

This section will present an overview of the paradigms which are most commonly used to assess working memory in both adults and children (for information about published working memory assessment batteries see Dehn, 2008; Strauss, Sherman and Spreen, 2006). However, it should be noted that the measurement of working memory is not straightforward and presents numerous challenges which may affect not only the choice of tasks which are used but also the interpretation of the study results. A critical issue in this respect is that there are different views, as has been previously discussed, regarding the sources of individual differences in working memory as well as the factors which constrain working memory capacity. Methodological issues can also affect the reliability and generalisability of study results. For example, Swanson and Siegel (2001) argue that as no task can be considered to be an entirely 'pure' measure of any particular process, there are problems associated with the use of only single measures of memory assessment as opposed to the use of multiple indicators, as all tasks reflect a certain amount of task variance (see Booth and Boyle, 2009, submitted). Swanson and Siegel also argue that many tasks that have been employed in the literature lack basic information on psychometric aspects such as reliability and validity. A further complicating factor that could affect the interpretation of study results could arise from differences in test administration. Friedman and Miyake (2005) have shown that different scoring methods are sometimes applied in studies, even for some of the most widely used tasks such as Daneman and Carpenter's (1980) classic reading span task. This can bring about substantial alterations in what such tasks measure (for further discussion of measurement issues see Jarrold and Towse, 2006; Savage et al., 2007).

These caveats having been noted, the most commonly used paradigm to explore individual differences in working memory is the measurement of memory span. Memory span is defined as the maximum amount of sequential information an individual can accurately remember (Gathercole, 1999). In general, memory span tasks are classified as either *simple span* tasks, which are said to measure storage capacity only, or *complex span* tasks, which are designed to measure storage and processing (Bayliss, Jarrold, Gunn, and Baddeley, 2003). Tasks designed to measure storage capacity only have their origins in the digit span procedure first devised by the schoolmaster Joseph Jacobs in late nineteenth century, the purpose of which was to measure the mental capacities of his students (Jacobs, 1887). Since then, many other tasks have been developed such as measurement of word span and letter span (e.g. Alloway, 2007; Pickering and Gathercole, 2001) and nonword span (Gathercole, Willis, Baddeley, and Emslie, 1994). All of these tasks require the participant to repeat back exactly sequences of number or words of increasing length, and all are said to provide an indication of the capacity of verbal short-term memory. Commonly used tasks to assess non-verbal short-term memory include the Corsi blocks task (Milner, 1971) and the Visual Patterns Test (Della Sala, Gray, Baddeley, and Wilson, 1997).

Assessment of complex working memory is generally carried out using paradigms that require simultaneous storage and processing of information. Daneman and Carpenter (1980) were the first to publish data on complex span performance using their reading span task. This task and its modifications are now amongst the most widely used to measure working memory. In such tasks, participants listen to a sentence read aloud, respond to a simple question about it, and then later must sequentially recall the final word of each sentence (for a critique see Waters and Caplan, 1996). This type of task assesses verbal working memory. Indeed, the majority of tasks designed to assess complex working memory have focused on the verbal domain, or have employed visuospatial tasks that place a heavy emphasis on verbal-phonological representations, such as the counting span task (Case et al., 1982). Although this task taps into the central executive and visuospatial memory, it also requires the participant to count out loud and recall the tallies, which places a heavy emphasis on phonological coding (Pickering, 2006). Tasks designed to measure visuospatial working memory without the involvement of the verbal domain have been less well-developed in the literature. Two examples of such tasks used in a study by Miyake, Friedman, Rettinger, Shah, and Hegarty (2001) are the letter rotation task (Shah and Miyake, 1996) and the dot matrix task (Law, Morrin and Pellegrino, 1995). In the letter rotation task, a set of the same capital letter is shown on a computer screen as either normal or mirror-imaged and rotated. The participant has to respond as quickly as possible with 'Normal' or 'Mirror' and also to remember the letter's spatial orientation. The sets progressively increase in size from two to five letters. In the dot matrix task, the main requirement is to verify a matrix equation while simultaneously remembering a dot location in a matrix grid. Miyake et al. argue that both these tasks involve visuospatial storage with a concurrent visuospatial processing requirement.

Currently, there are no well-developed tasks which measure the episodic buffer of the multicomponent (Baddeley, 2000) model. However, a task recently designed by Cowan and colleagues (Cowan, Saults, and Morey, 2006) was developed specifically to investigate the association of verbal and spatial information and thus may tap into the episodic buffer. Another task which it has been argued could provide an initial assessment of the capacity of the episodic buffer is sentence recall. Sentence recall is said to require the integration of information from short-term memory to support the verbatim recall of individual words and their order, with information from semantic memory (e.g. Alloway and Gathercole, 2005; Alloway, Gathercole, Willis and Adams, 2004). Both of these tasks may provide the foundations for future work in developing appropriate instruments to assess this newest component of the multicomponent model.

3.3 THE DEVELOPMENT OF WORKING MEMORY

Numerous studies have shown that all measures of short-term and working memory show a steady increase from the pre-school years through to adolescence (e.g. Bayliss et al., 2005; Case et al., 1982; Cowan, 1997; Fry and Hale, 1996; Hulme, Thomson, Muir and Lawrence, 1984; Isaacs and Vargha-Khadem, 1989; Siegel, 1994; Wilson et al., 1987). In addition, a body of research by Gathercole and colleagues (e.g. Alloway et al., 2004; Alloway, Gathercole and Pickering, 2006; Gathercole and Pickering, 2000b; Gathercole et al., 2004; Jarvis and Gathercole, 2003; Pickering, Gathercole, Hall, and Lloyd, 2001), which was guided by the basic tripartite model of working memory originally proposed by Baddeley and Hitch (1974), has provided evidence not only of the developmental changes taking place within individual components of working memory, but also how the organisation of the working memory system changes with age. The study by Alloway et al. (2004) extended this research to include an investigation of the episodic buffer.

Alloway et al. (2006) and Gathercole et al. (2004a) examined the working memory profiles of children ranging from 4 to 15 years of age using multiple assessments of all three main subcomponents of working memory. The findings suggested that the main components - the phonological loop, the visuospatial sketchpad, and the central executive - all appear to be in place by four years of age. The results of these and other studies also suggested that the capacity of each component increases linearly from age four to early adolescence, when they begin to level off to reach adult levels. However, some studies have reported different developmental trajectories for the visual and spatial aspects of short-term memory than those reported by Gathercole and colleagues, with much steeper age-related increases in the recall of visual patterns than block-tapping sequences (Logie and Pearson, 1997; Pickering et al., 2001). Gathercole et al. (2004) suggested that this could be due to the use of standardised scores in their (2004) study, which eliminated scaling differences between the visual and spatial tests used.

A number of explanations have been proposed to account for these developmental increases in working memory. Increases in the capacity of the phonological loop have been mainly attributed to an increase in the rate of rehearsal in children (Hulme et al., 1984). It has been shown that children do not spontaneously rehearse until about seven years old (see Gathercole and Hitch, 1993; for a review). However, other factors are also thought to be implicated which include changes in the speed of memory scanning during retrieval (Cowan et al., 1998) and output processes (Cowan et al., 1992).

Developmental increases in visuospatial memory capacity are thought to be partly attributable to a recoding of visuospatial information into a phonologic code in working memory (e.g. Pickering, 2001). As discussed in Chapter 2, it has been shown that around the age of seven, a developmental shift occurs when children begin to recode visual material where possible into a phonological code via rehearsal (e.g. Hitch et al., 1988; Hitch et al., 1989a,b; Palmer, 2000a). However, other more general factors have been suggested which could contribute to the observed increases in children's performance not only on visuospatial tasks but on all working memory task. These include changes in knowledge, processing strategies, and other abilities which may accompany the maturation of the neurological system such as increases in processing speed and attentional and processing capacity (Cowan, 1997: see also Pickering, 2001, for review).

Currently, there is no generally agreed explanation for developmental changes in complex working memory. As noted earlier, resource-sharing models suggest that increases in complex memory span performance across the early and middle childhood years are the result of more efficient processing strategies which release additional resources to support storage (e.g. Case et al., 1982). Other explanations based on theories of general working memory capacity are the task-switching accounts; as processing becomes more efficient more time is spent on refreshing items in storage (e.g. Towse and Hitch, 1995). Models arguing for domain specific as a well as domain general components of working memory such as the Baddeley model suggest that developmental increases in complex memory span tasks reflect increases in the processing efficiency of the central executive which in turn supports both the phonological store and the visuospatial sketchpad. For example, it has been shown that the principal neuroanatomical area associated with central executive function, the frontal lobes, has a developmental span that extends over a much longer period than that of other brain areas, from birth to adolescence (Nelson, 1995; cited in Gathercole et al., 2004a). It has therefore been argued that with increasing age children may be able to 'take greater advantage of the flexible strategic and processing resources provided by the central executive to enhance the limited storage capacities of the loop and the sketchpad systems' (Gathercole et al., 2004a, p. 179: for discussion of the development of complex working memory in children see Bayliss et al., 2005; Gathercole, 1998, 1999).

With respect to evidence regarding the structural organization of working memory, the research by Gathercole and colleagues provided evidence to suggest that the phonological loop and the visuospatial sketchpad were relatively independent of each other (Gathercole et al., 2004a; Jarvis and Gathercole, 2003; Pickering et al., 1998) supporting the absence of a direct link between these two slave systems in the Baddeley and Hitch (1974) model. However, the study by Gathercole and Pickering (2000b) with six- and seven-year-old children reported that whilst the phonological loop and the central executive were moderately associated with each other, the visuospatial sketchpad was not dissociable from central executive function. These findings are consistent with adult studies suggesting that visuospatial short-term memory tasks place significant demands on executive working memory, as discussed earlier in this chapter.

The study by Alloway et al. (2004) is reported to be the first study to investigate the episodic buffer in children. Findings of this study were reported to be consistent with a multicomponent working memory system consisting of a central executive, phonological loop, and episodic buffer (visuospatial memory was not examined in this study).

3.4 SUMMARY OF KEY POINTS

Working memory (WM) has been described as an active memory system that has the ability to store and simultaneously process information (Bayliss et al., 2005). Storage only components of the working memory system are generally referred to as short-term memory stores, although the precise use of these terms can vary with different theoretical models (Gathercole and Alloway, 2006).

There are several different theoretical perspectives on working memory (see Miyake and Shah, 1999). Arguably, the most developed and empirically validated as well as the most influential model is the multi-component model of working memory first developed by Baddeley and Hitch (1974) and later elaborated by Baddeley and his colleagues (1986, 1996a, 2000; Baddeley and Hitch, 1974; Baddeley and Logie, 1999).

Most current theories of working memory acknowledge the importance of attentional processes in carrying out tasks with a cognitive element (e.g. Engle, 2002; Cowan, 2005; Baddeley, 1986). The revised Baddeley and Hitch multicomponent model describes both an attentionally driven central control mechanism named the central executive and two subsidiary components specialised in maintaining information from different domains. A recently added component, the episodic buffer, is a multidimensional representation system capable of integrating temporary representations from other cognitive systems including components of working memory (Baddeley, 2000).

Experimental and neurological evidence has provided support for the modular structure of the multicomponent model. However, there is some evidence to suggest that the short-term visuospatial store of this model may not be completely dissociable from the central executive (e.g. Miyake et al., 2001).

Working memory is normally assessed using measurements of memory span. In general, memory span tasks are classified as either simple span tasks, which are said to measure storage capacity only, or complex span tasks, which are designed to measure storage and processing (Bayliss et al., 2003).

Strong relationships have been shown between complex working memory measures and measures of learning ability and academic attainments (e.g. Bull and Scerif, 2001; Cain et al., 2004; Daneman and Carpenter, 1980; De Jong, 1998; DeStefano and LeFevre, 2004; Engle et al., 1999b; Gathercole et al., 2006; Kyllonen and Christal, 1990; Ormrod and Cochran, 1988; Swanson and Jerman, 2007).

All measures of short-term and working memory have been shown to increase steadily from the pre-school years through to adolescence then start to level off to reach adult levels at around age 15 (e.g. Bayliss et al., 2005; Case et al., 1982;

Cowan, 1997; Fry and Hale, 1996; Hulme et al., 1984; Isaacs and Vargha-Khadem, 1989; Siegel, 1994; Wilson et al., 1987). Studies have also shown that the various components of the working memory system described by Baddeley and colleagues are in place by four years of age (e.g. Alloway et al., 2004; 2006; Gathercole et al., 2004a).

Developmental increases in the capacity of short-term and working memory components have been attributed to a range of factors. Increases in the capacity of the phonological loop are thought to be partly due to an increase in the rate of subvocal rehearsal in children (Hulme et al., 1994). Increases in the capacity of the visuospatial sketchpad may arise in part from children's developing ability to recode visual material where possible into a phonological code via rehearsal (e.g. Hitch et al., 1988, 1989b; Palmer, 2000a). However, maturational factors such as changes in knowledge, processing strategies, and other abilities which may accompany the development of the neurological system may also play a role in the development of both short-term and working memory components of the working memory system (Cowan, 1997: see also Pickering, 2001, for review).

This chapter has provided a review of the literature regarding different theoretical perspectives of working memory, with a focus on the multicomponent model of Baddeley and Hitch. As stated in the introduction, this model has been widely used to explore how working memory contributes to the development of a wide range of abilities and skills. Previous chapters on this literature review have examined the development of spelling in children and explored what the research has to say regarding the critical cognitive factors which might underpin this development. A particular emphasis has been placed on the role of working memory in spelling development. The next chapter will attempt to draw some of these elements together within a conceptual framework through which the development of spelling might be viewed from a working memory perspective.

CHAPTER 4. A CONCEPTUAL FRAMEWORK FOR SPELLING

4.1 OVERVIEW

This chapter will seek to develop a conceptual framework for spelling which incorporates some of the main ideas from cognitive models of spelling production with key perspectives on working memory. The aim of this framework is to provide an integrated account of the processes involved in spelling which addresses both learning to spell new words and the retrieval of words from long-term memory during spelling production. The framework incorporates a dual-route account of the spelling process (e.g. Barry and Seymour, 1988; Caramazza et al., 1987; Ellis, 1982; Kreiner and Gough, 1990; Morton, 1980) within the overall structure of the revised Baddeley and Hitch model of working memory (Baddeley and Hitch, 1974; Baddeley, 2000, 2007). Dual-route accounts of spelling represent the two main strategies it is thought spellers may use when spelling. The Baddeley and Hitch model of working memory provides the foundation to help explain some of the cognitive stages thought to be involved during both the acquisition of a new spelling word and the retrieval of a word from LTM. However, the discussion will also draw on concepts from other theories of memory and learning such as Vallar and Papagno's model of the phonological loop (Vallar, 2006; Vallar and Papagno, 2002), the working memory models of Cowan (2005) and Ericsson and Kintsch (2005), Paivio's dual-coding theory (e.g. Sadoski and Paivio, 2004), repetition effects (e.g. Hebb, 1961) and the importance of domain knowledge (e.g. Hambrick and Engle, 2002).

4.2 AN INTEGRATED FRAMEWORK FOR SPELLING

As we have seen from the literature review, successful spelling may depend upon a number of different cognitive and knowledge-based factors. For example, links have been demonstrated between verbal short-term and working memory (e.g. Ormrod, 1986; Ormrod and Cochran, 1988; Cormier and Dea, 1997; Savage et al., 2005;

Tijms, 2004), phonological awareness (e.g. Bradley and Bryant, 1983; Cornwall, 1992; Muter et al., 1998; Savage and Frederickson, 2006), and rapid automatic naming (e.g. Savage et al., 2005; Savage et al., 2008; Scarborough, 1998). Spelling has also been shown to draw upon a range of different sources of linguistic knowledge such as knowledge of letters (e.g. Muter et al., 1998), orthography and the morphological structure of words (e.g. Nunes and Bryant, 2009; Treiman et al., 1994), spelling rules (Rittle-Johnson and Siegler, 1999) and word-specific knowledge (e.g. Juel et al., 1986). The literature review has also provided some evidence to suggest that these factors do not work in isolation but rather that they operate in an interactive fashion to promote spelling development. This interactive process will now be considered using the integrated framework to guide the discussion.

4.3 LEARNING A NEW SPELLING WORD

4.3.1 Support from working memory

The integrated framework for spelling is shown in Figure 3. The framework might best be understood by following the paths that might be taken when learning to spell a new word using a well-known strategy such as 'look, say, cover, write, check'. The word *magician* will be used as an example.

The diagram shows the initial flow of information from the learning activity into the working memory system. According to Vallar and Papagno's (2002) account of the phonological loop, auditory input from 'saying' the word is first analysed and then fed into the short-term phonological store where it is held in a phonological form. Similarly, visual and kinaesthetic input from 'looking' and 'writing' the word enters and is held in the visuospatial sketchpad in a visuospatial code (see also Baddeley, 2003). The act of looking and writing may also result in parallel processing involving further articulation of parts of the word, such as the smaller word 'magic', or the word may be 'over-enunciated' as it is written to help with both segmentation and serial order of letters. These initial memory traces must now be continually refreshed otherwise they will decay rapidly (Baddeley and Hitch, 1974). The phonological representation is refreshed by a process of subvocal rehearsal which is said to occur via the articulatory rehearsal system (Baddeley et al., 1984; Vallar and Papagno, 2002). The memory traces held in the visuospatial sketchpad are also rehearsed, although the mechanisms here are less clear (Baddeley, 2000). It is suggested that this type of rehearsal, which also applies to rehearsal processes involved in other systems such as the episodic buffer, may reflect a more general process of attentional activation and re-activation (Baddeley, 2007).

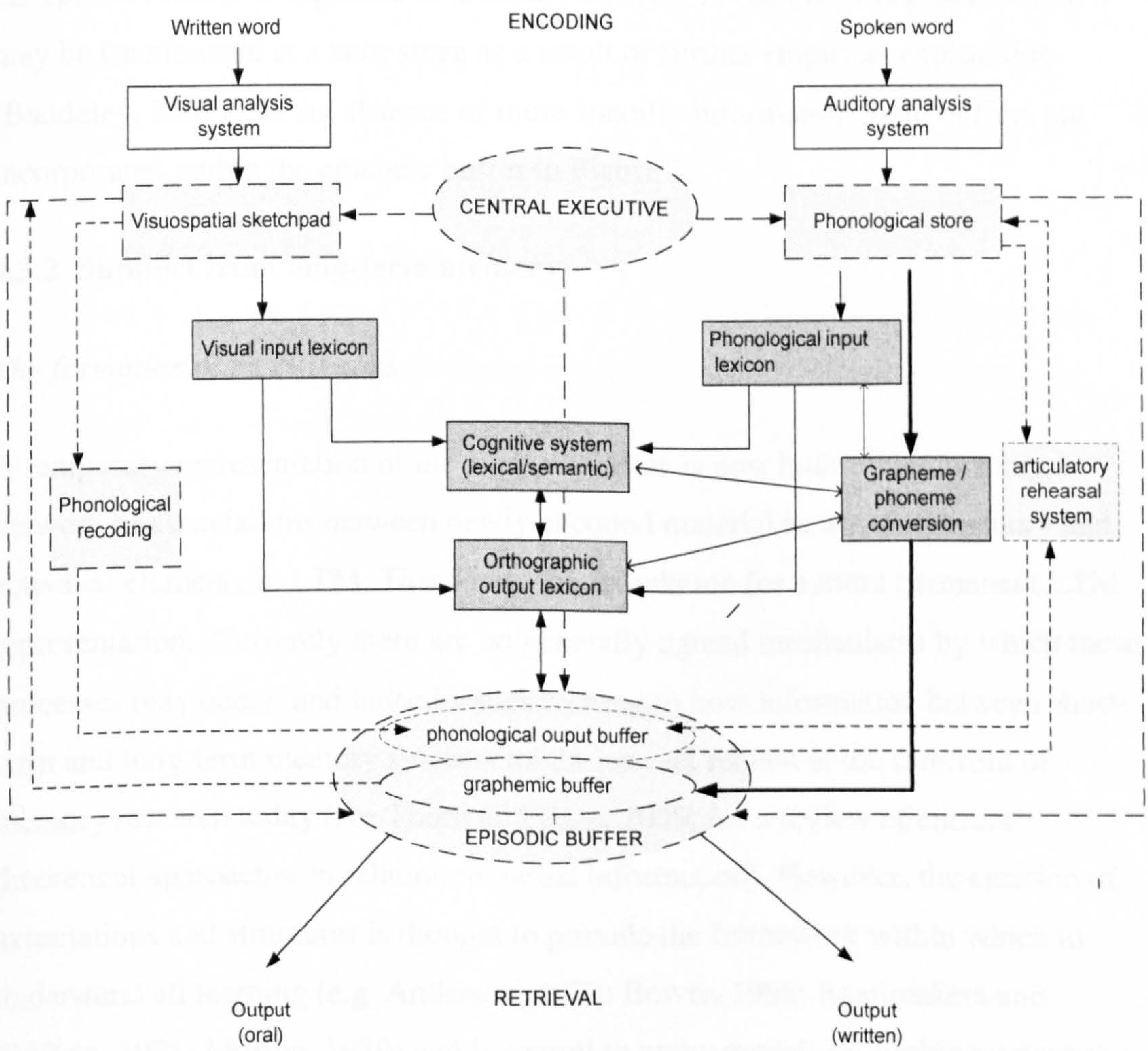

Figure 3. An integrated framework for spelling

The buffers which support these rehearsal processes are the phonological output buffer (e.g. Vallar, 2006; see also Baddeley 2003) and the graphemic buffer (e.g. Badecker, Hillis and Caramazza, 1990). Both of these buffers have been described in the literature as working memory buffers capable of holding memory representations of words as they are prepared for output, such as oral or written output. However, the relationship of these buffers with other components of working memory is underspecified. The buffers appear to correspond most closely to the focus of attention in Cowan's (2005) model of working memory and the episodic buffer of the Baddeley and Hitch model. Baddeley has suggested that at this stage of theorising, the episodic buffer is regarded as a unitary subsystem but that it is probable that it may be fractionated at a later stage as a result of further empirical exploration (Baddeley, 2007). In the absence of more specific information, both buffers are incorporated within the episodic buffer in Figure 3.

4.3.2 Support from long-term memory

The formation of associations

A temporary representation of the word *magician* is now built up by forming a network of associations between newly encoded material in working memory and activated elements in LTM. This forms the foundation for a more permanent LTM representation. Currently there are no generally agreed mechanisms by which these processes may occur, and indeed issues relating to how information between short-term and long-term memory systems might interact remain at the forefront of memory research today (see Thorn and Page, 2009, for a review of current theoretical approaches in relation to verbal information). However, the creation of associations and structures is thought to provide the framework within which to understand all learning (e.g. Anderson, 1973; Bower, 1998; Raaijmakers and Shiffrin, 1981; Morton, 1979) and is central to many models of working memory (e.g. Cowan, 2005; Ericsson and Kintsch, 1995).

Consider what an associated network for the word *magician* might look like. According to Ehri (1980, 1997) the most important early associations which require to be formed when learning to spell are those which bond sounds onto letters. The consolidation of letter-sound knowledge in LTM provides the foundation for the development of word-specific knowledge. Assuming there is partial or full knowledge of the alphabet, a 'first level' of associations might consist of phoneme-grapheme links. Within-word associations may also form between letters or syllables to help represent serial order. Spreading out from this, links could be formed with other information relating to the word held in LTM systems. For example, the word might activate its meaning in semantic memory. Morphological knowledge may also be activated, such as a recognition that the 'cian' ending is used for 'person words', for example, dietician and electrician, whereas the similar sounding 'tion' ending is used for abstract words such as addition or mention (e.g. see Nunes and Bryant, 2009). Stored lexical knowledge may help to create links with rhyming words to form analogies, such as *magic* with *tragic*. Links may also be formed with the sound of the word or parts of the word stored in the auditory system as well as with visual images of a *magician*. Ultimately, a whole network of associations for this word could develop incorporating both linguistic and non-linguistic features.

All of these associations together may increase the chance of activating the correct orthographic representation of the word at retrieval. In support of this, a recent study by Sadoski, Willson, Holcomb, and Boulware-Gooden (2004) using a large-scale national sample has shown that the more concrete and image-evoking a word the more likely it is to be spelled correctly. According to the authors, this is the first published study to include imageability as an independent variable in an investigation into factors which predict spelling performance. The authors interpret the positive effect of imageability on spelling in terms of Dual Coding Theory (e.g. Paivio, 1969; Sadoski and Paivio, 2004) which proposes that having two memory codes to represent an item provides a better chance of remembering than having only a single code. Sadoski et al. (2004) suggest that abstract words create associations between language representations, but concrete words additionally can activate visual images as well as semantic and lexical information.

Numerous studies have also shown that domain knowledge is a powerful determinant of cognitive performance (see Glaser and Chi, 1988, for review). In a study investigating the effects of working memory capacity, age, and domain knowledge on memory for prose passages, Hambrick and Engle (2002) found that by far the strongest predictor of the amount of information recalled was domain knowledge. Therefore, the greater the amount of linguistic information relating to spelling that is available to the speller, such as knowledge of orthographic rules, morphological principles, and known spellings of words, the greater the number of possible associations that can be made to strengthen memory for the word.

The phonological loop is thought to play a key role in facilitating associations with information held in LTM. This is supported by a body of research (see Baddeley et al., 1998, for review) into the role of the phonological loop in supporting the learning of new vocabulary words, leading to the proposal that the phonological loop may have evolved as language-learning device. These studies will not be discussed here. However, a general conclusion from the research was that it is not only the ability of the phonological loop to encode and temporarily store detailed sequences of phonological information that is important for learning, but also its ability to utilise these STM memory traces to activate aspects of LTM, demonstrating its "capacity to exploit prior learning" (Baddeley et al., 1998, p. 168).

Repetition

A further factor which could support the formation of associations is repetition. It has long-been recognised that repetition has a powerful and cumulative effect on learning and these effects are well-documented in the literature on learning and memory (see Crowder, 1976, for a review of repetition effects). In the classic study by Hebb (1961) it was also shown that repeated exposure to a stimulus helped individuals to learn even when they were not consciously aware of the repetitions.

From a working memory perspective, at a fundamental level initial memory traces have a life-span of only around two seconds and they must be immediately refreshed by subvocal rehearsal, which involves the silent repetition of auditory information (Baddeley et al., 1975), or re-activation of attention in the case of visuospatial information (Baddeley, 2000). Repeating the names of individual letters out loud and in sequence in a rote fashion when learning may help to strengthen the individual links between the letters and thus the memory for serial order of the letters. Repeating the whole word *magician* may help to keep the phonological representation of the word active and thus increase the opportunity to build-up associations with elements in LTM. Similarly, repeatedly attending to the visual form of the word and writing the word several times may help 'rehearse' the visuospatial form in working memory helping to build up associations with visual imagery in LTM. This may also help to strengthen associations between the visual codes for individual letters with their auditory codes. The issue of multiple coding will be discussed further in the next section.

4.3.3 Binding within the episodic buffer

As discussed in Chapter four, the formation of new links and associations for material held within working memory occurs via the episodic buffer. Figure 3 shows information from many different sources interfacing with the episodic buffer. The function of the episodic buffer is to bind this information together, as well as store these newly-formed representations while they are being prepared for output or transfer into LTM (Baddeley, 2000; 2007).

As yet, there is no well-developed cognitive theory which addresses the issue of binding within working memory. This is in contrast to the knowledge that has been gathered from research within the field of neuroscience, where questions regarding the nature of the binding mechanisms within and between sensory modalities have occupied researchers for many years. Much is now known about the neural mechanisms that bind information in LTM memory (see Murre, Wolters, and

Raffone, 2006, for full discussion). However, it is only within the last few years that cognitive psychology has begun to address the question of how differently coded information, such as information held in a verbal and spatial code, may be bound and maintained in working memory (e.g. Allen et al., 2006; Guérard, Tremblay, and Saint-Aubin, 2009; Jefferies, Frankish and Lambon Ralph, 2006; Jefferies, Frankish, and Noble, 2009; Rudner and Rönnberg, 2008).

One area which is of particular relevance to the present study in relation to binding concerns the implications for the use of multisensory techniques to support learning. It has already been argued that the formation of multiple associations and multiple coding with activated elements in LTM may support long-term learning (see also Baddeley, 2000; Hulme et al., 1997, for reviews of studies showing the influence of LTM on STM recall). From a working memory perspective, research has also shown that a target item is more likely to be recalled from short-term memory if it is presented in two sensory modalities rather than just one (see Penney, 1989, for review). However, although multisensory learning strategies have long been recommended to help children to read and spell by educationalists and by both government and independent bodies (e.g. DENI, 1998; DfES, 2007; Dyslexia Scotland, 2005; Gillingham and Stillman, 1997; Moats and Farrell, 2005), empirical evidence for the effectiveness of such strategies still comes from only a few studies. With respect to spelling, some studies have suggested that the use of combined visual, auditory and kinaesthetic strategies is more effective in learning to spell words than using only one sense, such as visual only, at least for children with literacy difficulties (e.g. Bradley, 1981; Hulme and Bradley, 1984; Thomson, 1988; 1991). However, more research in this area would be helpful not only in relation to the efficacy of such approaches, but also to explore the factors which may support or constrain their effects, in order to better understand the processes involved.

In relation to individual differences in the ability to benefit from multisensory approaches, one factor which may be important concerns the capacity of the episodic buffer, both in terms of the integrative ability of the buffer as well as its ability to temporarily maintain these integrated representations. Few investigations have been carried out to explore these issues, particularly with respect to possible relationships between episodic buffer functioning and the development of literacy skills. One study by Smith (2005) has reported that the episodic buffer made a unique contribution to receptive grammar development during middle childhood.

4.4 SPELLING A NEW WORD

Turning now to the steps involved in producing the spelling of a word, dual-route models suggest that there are two main strategies or routes the speller may use depending on whether the word is familiar or unfamiliar. The former uses a lexical route where the known word is directly retrieved from LTM, whilst the latter uses a sublexical route in which the word is assembled using knowledge of phoneme-grapheme correspondences (e.g. Barry and Seymour, 1988; Caramazza et al., 1987; Ellis, 1982; Kreiner and Gough, 1990; Morton, 1980; Patterson, 1986). It is now widely believed that these routes may interact during the spelling process, with spellers accessing each route as required (e.g. Kreiner, 1992; Miceli and Capasso, 2006; Rapp et al, 2002).

Using the framework to explore the stages involved in each of these processes, consider first the situation where the spelling of *magician* is known. The speller hears the word or silently articulates it. Auditory information is analysed and fed into the short-term phonological store. Then, perhaps through a process of 'spreading activation' (Anderson, 1983) within the network of associations established during the initial encoding of this word, the orthographic representation of the word stored in LTM is activated. Most dual-route models suggest that this occurs via the cognitive (lexical/semantic) system where the meaning of the word is first accessed (e.g. Barry and Seymour, 1988; Caramazza et al., 1987; Kreiner and Gough, 1990). However, some writers suggest that there may also be a more direct route to the orthographic output lexicon called the 'lexical nonsemantic' route which bypasses the cognitive system (Patterson, 1986: see also Ellis and Young, 1988, for a discussion of this and other possible routes which may be used when spelling to dictation). Evidence of this comes from instances of unconsciously written spelling errors, for example writing *their* instead of *there* (Morton, 1980, p. 125) but also neurological patients who seemed able to write words via a lexical route without being able to comprehend their meaning (Patterson, 1986).

Once the orthographic representation is accessed it then moves into the graphemic buffer where various other processes occur to prepare the word for either being written or spelled orally. This entire procedure may occur fairly automatically without the need for the involvement, or with minimal involvement, from the central executive. As suggested by Anderson (1983), it may be that the stronger and more extensive the associative network for a target item in LTM, the more automatic the process of retrieval may be.

Consider now the situation where the speller is not sure how to spell *magician*. This means that the word will have to be assembled letter-by-letter or letter string via the sublexical route using knowledge of phoneme/grapheme mappings. Using this route will require the speller to focus attention more directly on analysing the sound structure of the word drawing on additional skills such as phonological awareness.

If this route is used in isolation, a number of different phonologically plausible spelling errors may result, such as *majishion*, *magicion* etc., as well as the correct spelling. However, as stated earlier it is more likely that the speller will use this route in conjunction with the lexical route to form the word, with the result depending to some extent on acquired knowledge. For example, the speller may be able to retrieve part of the word from the orthographic lexicon and assemble the rest, thus switching between routes. The word, or part of the word, may also be spelled by analogy, drawing on stored knowledge of orthographic and morphological information. All of these strategies may involve the learner in more active processing thus drawing on additional working memory resources.

During the spelling process it is also possible that various feedback mechanisms will be alerted, regardless of which route is used, to allow the speller to make corrections if necessary. If the word is spelled incorrectly, the resulting visual image (or auditory feedback if the word is spelled orally) may then enter the system via the appropriate channel to re-activate the correct representation.

Both spelling routes involve working memory as described. However, the precise nature of working memory involvement may depend on the processing demands of the spelling task. Some support for this comes from the study by Kreiner (1992) which investigated skilled spelling with a view to testing predictions of a dual-route model of spelling. The results suggested that skilled spellers used both spelling routes in parallel when spelling difficult words. The study also found that there was a significant correlation between verbal working memory, but not verbal short-term memory, and the difficulty of the word being spelled.

4.5 SUMMARY AND RESEARCH QUESTIONS

This chapter has proposed an integrated framework for spelling which considers the stages which may be involved in learning new words and also the retrieval of words when spelling. The framework emphasises a continuous interaction between different sources of knowledge and memory systems during these processes. It is not suggested that the framework can fully account for all of the possible stages which may occur within such integrated operations. This is partly to do with the complex nature of the spelling process. However, it is also because many of the mechanisms underlying the steps described within the framework are not yet fully-understood. For example, questions regarding how information may be shared between lexical and sublexical processes during spelling production (e.g. Folk and Rapp, 2004), the nature of the orthographic representations held in the orthographic output lexicon (Miceli and Capasso, 2006) and the role of the graphemic buffer in spelling (Tainturier and Rapp, 2004) continue to present challenges for researchers. Within the area of memory research, key issues which are currently being explored include cross-modal binding within working memory (e.g. Allen and Baddeley, 2006; Guérard et al., 2009; Saults and Cowan, 2007) and the interactions between long-term linguistic knowledge and verbal short-term memory (e.g. Jefferies et al., 2009; see also Thorn and Page, 2009, for a review of current theoretical approaches). One area, however, about which relatively little is still known but which has attracted considerably less attention in the literature concerns the nature of the interactions and relationships between working memory and spelling. The research being conducted as part of this present study attempts to address this by carrying out two main investigations into working memory and spelling. The first investigation explores the relationship between working memory and spelling ability. The second examines the effects of multisensory strategies in helping children learn to spell from a working memory perspective.

The following research questions are addressed:

1. What is the relationship between working memory and spelling ability? (Study 1)
2. Do multisensory spelling strategies assist children in learning to spell? (Study 2: Part I)
3. How adequately can the Baddeley and Hitch multi-component model account for performance in learning to spell using such strategies? (Study 2: part II)

CHAPTER 5. METHOD

5.1 PARTICIPANTS

Five primary 5 classes from four schools within the Renfrewshire area took part in this research. All of the pupils with one exception took part. The sample comprised 127 participants, 57 girls and 70 boys, (mean age 9 years 4 months, SD 3.80 months). All the children had English as a first language. One child was withdrawn. This was a child with autism and the teachers and parents agreed that the child would find the study too stressful. For the sample of 126 children who eventually took part in this study, data from two pupils was deleted because their absences meant that little information had been gathered for these two children. The final data used for the analysis therefore came from 124 pupils.

Following a request to the Educational Psychology Service for names of schools within the authority who might be interested in taking part in this research, three schools were approached. The initial approach to the schools was made by a telephone call to the headteacher from the researcher. This was followed by a visit to each school to discuss the study in more detail. The initial sample of schools contained three schools and four classes. Preliminary discussions were held and consent letters sent out to all parents. However, one of the schools had to drop out as the class had been using a spelling strategy very similar to the SOS method to be used in the training study. Another school then had to be found. Two were approached and both gave consent and were included bringing the total number of schools to four and classes to five. Three of the schools were of a similar size and had one primary five class each. The fourth school was larger and had two primary five classes. The demographic profiles of the schools is given in Appendix A.

5.2 GETTING CONSENT

All schools provided contact details of the children and letters were sent out to parents from the Educational Psychology Service describing the study and seeking permission for their children's participation (see Appendix B). No parent whose permission was sought refused. Only one child was not asked to take part. This was a child with autism. The teachers felt, and the parents agreed, that the child would find the study too stressful.

Ethical approval for the study was granted by the Renfrewshire Council Educational Psychology Service Research Ethics Board and the University of Strathclyde Ethics Committee.

5.3 STUDY 1

5.3.1 Study Aim

To investigate the relationship between working memory and spelling ability.

5.3.2 Design

A multiple regression design was used

5.3.3 Sample

126 participants, 57 girls and 69 boys, (mean age 9 years 4 months, SD 3.80 months) from four schools within the Renfrewshire area took part in this study. There were two main reasons for choosing an older primary age group for this research. First, given that whole class groups were taking part, the ability of children to work independently during the three-week training intervention was an important factor. Second, by the age of nine most of the children would be expected to be at or moving towards the orthographic stage in spelling (Frith, 1985) where it is suggested that in addition to phonological skills, other skills and sources of knowledge such as visual skills, and semantic and syntactic knowledge become increasingly more important for spelling (e.g. O'Sullivan and Thomas, 2007: Pattison and Collier, 1992). However, few studies have actually explored the degree to which components of working memory, including phonological short-term memory, may be important for spelling in this age group of children.

5.3.4 Procedures

All pupils were:

a) tested in their class groups for spelling using a standardised spelling test administered by the class teacher. The test took approximately 30-40 minutes to administer.

b) tested individually in three aspects of working memory by the researcher or a graduate research assistant. Testing took place in quiet rooms in the children's schools. The duration of testing varied between approximately 10 to 20 minutes for each child.

5.3.5 Assessment Measures and Reliability

Spelling

The spelling test used was the nferNelson single word spelling test (Sacre and Masterson, 2000). The pupils completed test C which comprises 45 items. In this test children were asked to write single words to dictation. Each word was presented on its own, then in a sentence, then on its own again. The raw score is the number of words spelled correctly. The test-retest reliability coefficient for this battery of tests ranges from 0.98 to 0.87.

Raw scores and not standardised scores were recorded. This was because words for each test in this battery are selected to match a year stage (England) or primary (Scotland). However, the manual advises that if the test is being administered in the first term, then the test for the previous year stage could be used. Separate discussions with three of the class teachers indicated that all three teachers felt that the test for the primary five stage seemed very difficult and that the earlier test would still 'stretch' even the good spellers. Given this information and also the fact that the test was being administered in the first term, it was decided to administer the test for the earlier stage, as suggested in the manual. However, when raw scores were being converted to standardised scores the ages of some of the children put them outside the range of standardised scores presented in the manual. The tables stopped at 9 years 2 months and many of the children in the sample were older.

Discussions then took place with the test publishers but there were no additional tables available (although the publishers agreed that future users of the test should be alerted to this potential difficulty). To control for this lack of standardisation, spelling scores were entered as raw scores in the analysis and age was also entered as a variable.

Working memory

The three subtests used were selected from the *Working Memory Test Battery for Children* (WMTB-C; Pickering and Gathercole, 2001).This test uses the multi-component WM model originally proposed by Baddeley and Hitch in 1974 with subsequent modifications (Baddeley, 1986, 2000; Baddeley and Hitch, 1974, 1994) as its theoretical basis.

Each subtest was chosen to measure one aspect of the multi-component WM model. The subtests used were Digit Recall, Visual Patterns Test (Della Sala et al., 1997)[2] and Backward Digit Recall to measure the phonological loop, the visuospatial sketchpad and the central executive respectively.

In the *digit recall* test, the examiner speaks a sequence of digits to the child at a rate of one digit per second and the child is asked to recall them in the correct order. The lists of digits have been randomly chosen from digits 1 to 9 with no digits repeated in a list. Following a practice session, testing commences with single-digit lists, which

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[2] The Visual Patterns Test was originally developed for use with adults but has been standardised for use with children (Pickering and Gathercole, 2001). However, although standard scores for children are provided in the manual for the WMTB-C (Pickering and Gathercole, 2001), at the time of testing the test had to be purchased separately from the test publishers. In addition, instructions for administration and scoring the test when used with children were not available either in the original Visual Patterns Test or in the WMTB-C and had to be obtained from the authors of the WMTB-C. The writer was informed that it was anticipated that the VPT would be linked more clearly to the WMTB-C in the future. However, recent information suggests that these plans have been shelved and that the status of the VPT is unclear with respect to the WMTB-C.

is increased by one at each level. The examiner moves on to the next level whenever the child recalls four of the sequences at that length correctly. A maximum of six lists is presented at each length. The child is credited with all six lists at that length if the first four trials are correct. For more able children, the test can be started at the block that corresponds to the greatest span (2 or 3) and the child is credited for all unadministered trials following correct recall. The raw score is the number of lists recalled correctly. The mean test-retest reliability coefficient for this measure is .82 for 9- to 11-year old children.

The *backward digit recall* is similar to the digit recall test except that the child is asked to recall the digits in the reverse order and the starting point is two digits. Also, given that children commonly make errors with three digits, the 2-item practice trial is immediately followed by the 2-item test trial. If the child responds correctly the 3-item practice trial is presented followed directly by the remainder of the test trials. The mean test-retest reliability coefficient is .71 for 9- to 11-year old children.

In the *visual patterns test* the child is shown a two-dimensional grid composed of equal numbers of filled (black) and unfilled (white) squares in matrix or grid. After having viewed the grid for three seconds, the child is then presented with an empty grid of the same size and asked to recall the location of the black squares in the pattern studied by marking them onto the empty gird. The complexity of the grid is increased until recall falls below threshold levels of accuracy. At the time of writing, no data regarding test-retest reliability was available for this test.

Interscorer agreement

All working memory test papers were checked and interscorer agreement was 97%. Teacher-corrected spelling tests were also checked. Interscorer agreement was 100%.

5.3.6 Results

For the sample of 126 children for whom parental permission to take part in the study was obtained, data from two pupils was deleted because of long absences. Therefore, a total of 124 pupils contributed data to this study. For Study 1, all 124 pupils completed the standardised spelling test. However, some of the children were not present when the working memory tests were administered and complete data for the regression analyses was only available for 114 children. The results are reported below. For consistency of reporting, the working memory subtests are referred to as digit span forwards (DSFwds), digit span backwards (DSBwds) and visual patterns span (VPS).

Preliminary inspection of data

Preliminary inspection of the data showed that the spelling data exhibited signs of marked negative skew ($z = -3.146$, $p < .01$). Descriptive statistics showed that the 5% trimmed mean was not very different from the actual mean (32.63 compared with 32.11), which suggested that extreme scores were not having a strong influence on the mean. Visual examination of the normal Q-Q plot suggested only minor deviations from a straight line. A square root transformation was also explored. As the data was negatively skewed the scores were first reflected, that is, each score was subtracted from the largest value that the variable could have plus 1 (Pallant, 2007). This did improve the distribution. However, the findings of the statistical analyses for both forms of the data were very similar. Therefore for the sake of interpretability, the untransformed data is reported.

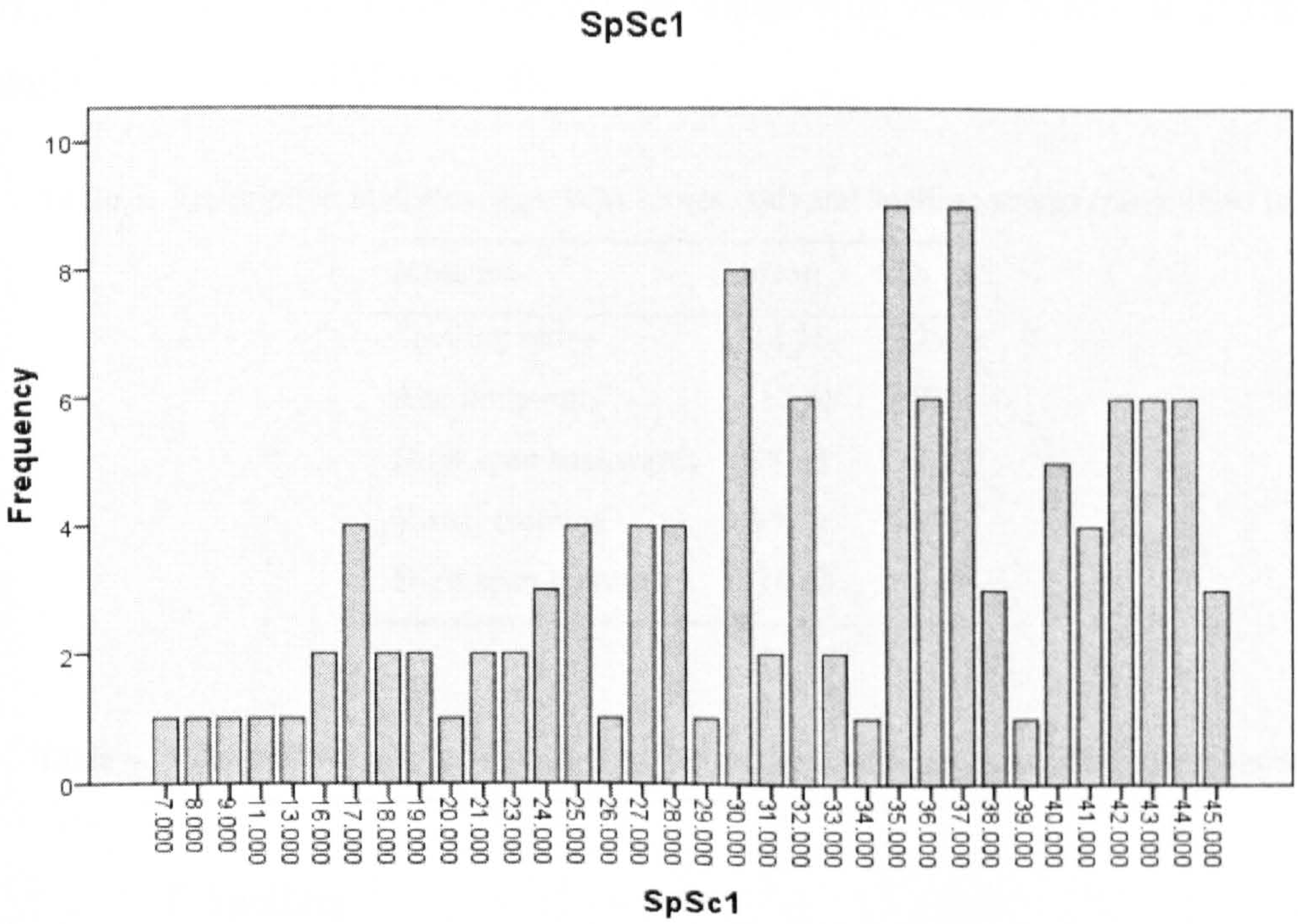

Figure 4. Bar chart showing pupils' baseline spelling scores (SpSc1) on the nfer NELSON spelling test

Exploring the Relationships between Working Memory and Spelling

Multiple regression was used to explore the relationships between working memory measures and spelling ability. Standard scores were used for all working memory measures. As discussed previously standard scores for the spelling measure could not be calculated for all children so raw scores were used and age was entered as an additional independent variable in the regression analyses. A summary of the descriptive statistics for each variable is presented in Table 3. Correlations between the variables are presented in Table 4. As can be seen, the correlations between spelling and working memory measures were all moderate to low in strength, although all correlation coefficients were significant. The highest correlation was between spelling and verbal short-term memory ($r = .35$) which was significant at the .001 level. The measures of working memory were all significantly correlated with each other, with the strongest correlation being between verbal ST and verbal WM (r = .31). Visuospatial STM was modestly correlated with verbal WM (r = .23) and less strongly with verbal STM (r = .19).

Table 3. Descriptive Statistics: age, WM scores (std) and spelling scores (raw). (N=114)

Measure	Mean	SD
Spelling score	32.11	9.29
Age in months	112.41	3.77
Digit span backwards	98.68	17.78
Visual patterns	95.78	13.87
Digit span forwards	110.65	19.60

Table 4. Inter-correlations between spelling score, age and working memory components

	1	*2*	*3*	*4*	*5*
1. Spelling	-				
2. Age	-.07	-			
3. Digit span forwards	.35***	-.08	-		
4. Digit span backwards	.24**	-.15	.31***	-	
5. Visual pattern span	.22**	.04	.19*	.23**	-

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

Regression analysis 1.1

As a first step, all predictors were entered simultaneously into the regression equation. Tables 5 and 6 provide regression information for this analysis. A significant model emerged: $F_{4, 109} = 5.21$, p = .001 (see Table 5). The model accounted for 13.0% of the variance of spelling ability (adjusted $R^2 = 0.13$). Only digit span forwards was a significant predictor of spelling ability.

Table 5. Model summary for regression 1.1 with all variables entered simultaneously

Model	*R*	R^2	*Adjusted* R^2	*Std.Err of Estimate*	*F*	*df1*	*df2*	*Sig. F*
1	.40[a]	.16	.13	8.669	5.21	4	109	.001

a. Predictors: (Constant), pattern span, age mths, digit span backwards, digit span forwards

Table 6. Simultaneous multiple regression of predictors of spelling scores on standardised test.

Variable	B	SE B	beta	t	Sig
Chronological age	-.088	.220	-.036	-.402	.689
Digit span forwards	.134	.044	.282	3.029	.003*
Digit span backwards	.060	.05	.114	1.205	.231
Visual pattern span	.098	.061	.146	1.599	.113

*p< .005

Regression analysis 1.2

A fixed-order hierarchical regression was carried out to find out how much unique variance was accounted for by digit span forwards. Age, pattern span and digit span backwards were entered into the equation in the first block. Digit span forwards was then entered into the second block. Tables 7 and 8 give information for this analysis.

Table 7. Model summary for hierarchical regression with digit span forwards entered last

Model	R	R Square	Adjusted R Square	Std.Err of the Est.	R Square Change	F Change	df1	df2	Sig. F Change
1	.30[a]	.09	.07	8.986	.09	3.62	3	110	.015
2	.40[b]	.16	.13	8.669	.07	9.18	1	109	.003

a. Predictors: (Constant), pattern span, age mths, digit span backwards
b. Predictors: (Constant), pattern span, age mths, digit span backwards, digit span forwards

Table 8. Hierarchical multiple regression of predictors of spelling scores

Blocks	B	SE B	Beta	t	Sig
Block 1					
Chron Age	-.115	.227	-.047	-.508	.613
DSBwds	.100	.050	.191	2.019	.046*
Patt span	.122	.063	.181	1.935	.056
Block 2					
Chron Age	-.088	.220	-.036	-.402	.648
DSBwds	.060	.050	.114	1.205	.231
Patt span	.098	.061	.146	1.599	.113
DSFwds	.134	.044	.282	3.029	.003*

*p <.005

The results show that in Block 1, a significant model emerged, $F_{3,110} = 3.62$, $p = .015$, with age, digit span backwards and visual pattern span accounting for around 6.5% of the variance (adjusted $R^2 = .065$ - see Table 7). However, when digit span forwards was entered in Block 2 only this was significant, accounting for a unique variance of 7%. The final model accounted for 13.0% of the total variance (adjusted $R^2 = .13$).

5.3.7 Summary of Results

The results suggest that working memory components accounted for around 13% of the variance in spelling ability. However, verbal short-term memory was the only significant predictor when all the components of working memory were taken into account, contributing an additional unique variance of 7% to spelling performance. This result appears to suggest a key role for the phonological loop in learning to spell new words.

5.4 STUDY 2: PART 1

5.4.1 Study Aim

To investigate the effectiveness of multisensory spelling strategies in helping children learn to spell new words.

5.4.2 Design

Within-subjects training study

5.4.3 Sample

All of the children who took part in study 1 also took part in study 2.

5.4.4 Materials

Teachers:	Training handbook (see Appendices C to O).
Pupils:	Pre-test response sheet (see Appendix J).
	A4 sheets with words printed across the top of sheet. One sheet for each word set (see Appendix L).
	Strip of white card for covering words.
	Pencils/ rubbers.

All record sheets prepared for teachers included pupil names for ease of recording.

5.4.5 Procedures

A within-subjects repeated-measures design was used. The pupils learned to spell new sets of words under three different conditions, specifically, by using three different spelling strategies. The conditions were implemented consecutively for one week at a time over a period of three weeks. The pupils learned a new set of ten words each week, making a total of thirty words.

The presentation order of training conditions remained constant which meant that the same condition was being implemented across all schools at the same time. It was envisioned that each strategy would build on the previous one thus minimising any treatment effects. Sets of words were counterbalanced across classes, i.e. one class would learn set 1 in week one, set 2 in week two and set 3 in week three, another class would learn set 2 in week one, set 3 in week two etc. This controlled for possible differences in word difficulty between the words sets. To control for words the children might already be able to spell the children were given a pre-test of the 30 training words one week before the training began.

Selection of words

In order to maximise the number of words selected for training that would be unknown to the pupils, the pupils' spelling test papers from study 1 (the nferNelson single word spelling test) were analysed. The ten words most often spelled incorrectly were extracted. These ten words were spelled incorrectly by between 52 - 74% of the pupils depending on the word. Using the structured spelling lists from the nferNelson manual, three words to match each of these words in terms of components in the words and overall level of difficulty were selected. One of each of these words was then randomly allocated to a word set to make three sets of ten words. The three words sets were then compared by four of the class teachers and judged to be comparable in terms of level of difficulty,

General Instructional Procedures

At the start of each training week the children were given out a double-sided A4 sheet of paper containing the words to be learned. Each side of the paper was divided into five columns. Each column contained a word to be learned printed at the top, making five words to each side of the page. The space remaining under the word in each column was for pupil use (see Appendix L).

For four consecutive days each week (Monday to Thursday) the children were engaged in learning to spell the words for a period of up to 15 minutes. Each day the children were encouraged to concentrate on three new words with revision of any words learned the previous day(s). The training period was followed by a Friday end-of week test. Follow-up tests were given at three weekly intervals after each training week.

Training conditions

Week 1. The children were told they could learn the words any way they choose. They were given no other instructions except that they were could use the space underneath the words to write on if they wished and they were to work alone. This condition was called the *General* condition.

Week 2. The children used the Look, Say, Cover, Write, Check (SACAWAC) method. All the children were given instruction in the SACAWAC method on day one[3]. The instructions given to the children were: "1. ***Look** at the shape of the word. Can you see any patterns or groups of letters that go together? Are there any words within words? 2. **Say** the words carefully and slowly to yourself. Try to listen for the sounds in the words. 3. Now **Cover** the word. Try to picture the word in your mind, closing your eyes might help you to do this. 4. Say the word again and then **Write** the word down. 5. **Check** to see if it is correct. If the word isn't quite right don't worry, just try again. It can often take a few attempts to get it right.*" The children were told to repeat this procedure until they had written the word correctly at least three times. The teacher demonstrated the method on the board using a sample word. The words

[3] Prior to embarking on this study, the writer consulted with teachers in the schools she visited regarding the spelling strategies they used. The SACAWAC method was one of the most commonly mentioned strategies. However, teachers also stated that they did not explicitly teach this strategy or any other strategy as a matter of course by the time children reached primary five. There is no evidence, however, regarding the extent to which pupils in the study sample may have been aware of this strategy and also if they used it (although see Discussion, Chapter 6.)

Look, Say, Cover, Write, Check, were left on the board as a reminder. This condition was called the *SACAWAC* condition.

Week 3. In the third and final week children used the simultaneous oral spelling method (SOS)[4]. The instructions given for this strategy were similar to the SACAWAC method in that the children were instructed to *Look* and *Say* the word as before. However, before going on to cover the word they were then told to *"Copy the word and say **each letter name as it is being written**"*. Then they had to *Cover* the word and write it again as before, saying each letter name out loud as it was written. This was repeated until they had written the word correctly three times. This condition was called the *SOS* condition.

5.4.6 Training and Treatment Fidelity

To ensure fidelity of treatment, teachers were given a training handbook with lesson plans and scripts for each lesson or activity. The researcher also met with the teachers individually at the start of the project to go over all the instructions. The researcher also visited each of the schools once a week for the first three weeks to discuss any issues and was also available by phone or e-mail.
To monitor pupil activity and involvement in the training, teachers used observation checklists for each day (see Appendix M).

5.4.7 Assessment Measures and Reliability

Pre-test scores. To control for words already known, all pupils were given a pre-test of the thirty words for training one week before the training began. These were scored by the teacher and scoring checked by an independent observer.

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[4] The SOS method was likely to be an unknown method for most of the children.

Post-test scores. Outcome measures for posttest scores were the total number of words spelled correctly out of ten. Pupils completed three end-of week spelling tests and a maintenance test at intervals of three weeks after each condition. These end-of week tests were corrected by the class teachers. It was not practical to check teachers' scoring of every pupil's end-of week tests. However, transfer of scores onto pupil record sheets was checked by two independent observers by comparing the scores marked on the pupils' papers and those recorded on the record sheet.

5.4.8 Results

Analysis of short-term effects of intervention

A preliminary data analysis was carried out to find out if there was any overall effect of intervention. Complete pre- and post-intervention data for each approach was available for 109 pupils. A 3 x 2 repeated measures analysis of variance was carried out using General x SACAWAC x SOS (strategy) and pre-and post-intervention (time point) as factors. Descriptive statistics showing means and standard deviations for the pre- and post-intervention data are provided in Table 9.

Table 9. Descriptive statistics showing means and standard deviations for the factors used in the 3 x 2 analysis of variance

	Mean	SD	N
PreGen	3.68	3.37	109
PreSAC	3.38	3.11	109
PreSOS	3.38	3.03	109
PostGen	7.46	3.13	109
PostSAC	7.21	3.17	109
PostSOS	6.85	3.14	109

The results showed that there was a significant main effect of training (time point), $F_{(1,108)} = 353.50, p < .001$. There was also a significant main effect of strategy, $F_{(2,216)} = 4.46, p = .013$, but no interaction between the two factors, $F_{(2,216)} = 1.21, p = .302$, which indicates that there was no difference between the three strategies in terms of number of words learned across the pre- and post-intervention time points.

The significant main of strategy indicated that at least one of the strategies differed from the other two at both pre- and post-intervention. Contrasts showed that there was no difference between the General and the SACAWAC strategy ($p = .065$) or between the SACAWAC and SOS ($p = .264$), but there was a significant difference between the General and SOS ($p = .003$). This was attributed to sampling error. Inspection of the data showed that there was a higher pre-test baseline score for words in the General condition than in the other two conditions although the sets of words which formed the baseline scores for each condition were counterbalanced across all classes.

Table 10 shows the mean number of words learned in each of the different conditions.

Table 10. Mean number of words learned using the different strategies

General	SACAWAC	SOS
3.78 SD 2.79	3.83 SD 2.56	3.47 SD 2.26

Analysis of maintenance effects

A preliminary data analysis was carried out on pre- and follow-up data to explore to what extent the words the pupils learned were maintained after three weeks. Complete pre- and follow-up data for each approach was available for 103 pupils. A 3 x 2 repeated measures analysis of variance was carried out using General x SACAWAC x SOS (strategy) and pre-and follow-up (time point) as factors.

Descriptive statistics showing means and standard deviations for the pre- and follow-up data are provided in Table 11.

Table 11. Descriptive statistics showing means and standard deviations for the factors used in the analysis of maintenance effects.

	Mean	SD	N
PreGen	3.85	3.38	103
PreSAC	3.34	3.13	103
PreSOS	3.55	2.99	103
FLUPGen	6.84	3.24	103
FLUPSAC	6.01	3.48	103
FLUPSOS	5.99	3.41	103

The results showed that there was a significant main effect of training at follow-up (time point), $F_{1.102} = 243.82$, $p < .001$. There was a significant main effect of strategy, $F_{2,204} = 10.20$, $p < .001$. There was no interaction between the two factors, $F_{2,204} = 2.48$, $p = .086$, again indicating that no one strategy resulted in a significantly greater number of words being retained at follow-up.

Contrasts showed that there was no difference between the SACAWAC and the SOS strategy ($p = .564$). There was a significant difference between the General and the SACAWAC strategy ($p < .001$) and a significant difference between the General and SOS ($p =.001$). However, again this was attributed to sampling error as previously outlined.

Table 12 shows the mean number of words maintained at follow-up for the three different strategies.

Table 12. Mean number of words maintained at three week follow-up

General	SACAWAC	SOS
2.98 SD 2.52	2.68 SD 2.28	2.44 SD 1.95

5.4.9 Summary of Results

The findings showed that the three strategies used here resulted in the children being able to spell significantly more words at post-intervention compared with pre-intervention. They also continued to spell correctly significantly more words at a three-week follow up than they did at pre-intervention, although at follow-up the total number of correctly spelled words had decreased slightly. The absence of a significant interaction between the factors at both post-intervention and follow-up showed that, at least within the parameters of this training study, no one strategy was significantly better than any other in helping the children to learn to spell new words or to maintain these words. Overall, there was a trend for the pupils to learn and also retain slightly less words using the SOS than when using the other strategies.

The significant main effect of strategy at both post-intervention and follow-up is attributed to sampling error caused by a higher pre-test score in the General condition, despite the fact that sets of words were counterbalanced across all five classes.

5.5 STUDY 2: PART II

5.5.1 Study Aim

To explore how adequately the Baddeley and Hitch multi-component model of working memory could account for performance in learning to spell using each of the strategies adopted in Part I.

5.5.2 Design

A multiple regression design was used.

5.5.3 Sample

As in Studies 1 and 2.

5.5.4 Procedure

To explore the contribution of working memory to performance in learning to spell using different strategies, multiple linear regressions were carried out using the new words learned for each strategy as the dependent variable and the pupils' scores for digit span forwards, digit span backwards and visual pattern span as independent variables.

The index used in the analyses for new words learned was the G-ratio (McGuigan, 1978). An examination of correlations had found significant negative correlations between pre-intervention and number of new words learned. Therefore, G-ratios were constructed instead of gain scores. G is defined as the ratio between the amount actually gained and the amount that could have been gained. According to McGuigan (1978), a G-ratio is a more sensitive index than a gain score as the amount that can be gained is not artificially restricted for students who perform at a high pre-test level or inflated for students who perform at a low pre-test level.

The formula for computing G is:

$$G = \frac{\text{Actual gain (post-test score minus pre-test score)}}{\text{Possible gain (maximum possible score minus pre-test score)}}$$

Calculation of actual gain

The actual gain by each pupil (number of new words learned) under each condition first had to be determined before the G-ratio could be calculated. This was done by subtracting the pupil's post-test scores from their pre-test scores for each condition (i.e. post-General score minus pre-General score; post-SACAWAC score minus pre-SACAWAC score; post-SOS score minus pre-SOS score).

It may be appropriate at this point to describe how the separate pre-tests scores for each condition were indentified. Each pupil's pre-test response sheet was analysed and the thirty words were divided into three different sets using colour coding, one colour for each set of training words. The scores were then recorded in the SPSS data set. All stages in this analysis were checked by at least one independent examiner.

5.5.5 Results

Using the G-ratio as the dependent variable (the index of new words learned) for each strategy (i.e. G-Gen, G-SAC, and G-SOS), and the three working memory component scores as independent variables, the analysis found that significant models emerged for all strategies, accounting for around 10% of the variance in each case: for the General strategy, $F_{(3, 114)} = 4.62$, $p = .004$; for the *SACAWAC* strategy, $F_{(3, 110)} = 5.72$, $p = .001$; for the *SOS* strategy, $F_{(3, 112)} = 5.13$, $p = .002$.

Model summaries are presented in Table 13.

Table 13. Model summaries for all independent variables

Model	*R*	*R Square*	*Adjusted R Square*	*Std.Err of Estimate*	*F*	*df1*	*df2*	*Sig. F*
1a	.33	.11	.09	.333	4.62	3	114	.004
1b	.37	.14	.11	.303	5.72	3	110	.001
1c	.35	.12	.10	.30945	5.13	3	112	.002

Models: 1a. Dep. var. G-Gen; 1b. Dep. var. G-SAC; 1c. Dep. var. G-SOS
Predictors: (Constant), VPS, DSFwds, DSBwds

Significant model predictions were found for each of the strategies (see Tables 14, 15 and 16). For the General strategy, visual pattern span was a significant predictor ($t = 2.21$, $p = .029$). For the SACAWAC strategy, visual pattern span was also a significant predictor ($t = 2.08$, $p = .040$), although digit span forwards was approaching significance ($t = 1.94$, $p = .055$). For the SOS strategy, visual pattern span was no longer significant. Digit span forwards was significant ($t = 2.34$, $p =$ .021) and digit span backwards was approaching significance ($t = 1.94$, $p = .054$).

Table 14. Regression analysis for the General strategy

GENERAL	B	SE B	Beta	t	Sig
DSFwds	.002	.002	.095	1.026	.307
DSBwds	.003	.002	.166	1.770	.079
Vis Patt span	.005	.002	.203	2.209	.029

Table 15. Regression analysis for the SACAWAC strategy

SACAWAC	B	SE B	Beta	t	Sig
DSFwds	.003	.002	.179	1.94	.055
DSBwds	,003	.002	.157	1.664	.099
Vis Patt span	.004	.002	.192	2.081	.040

Table 16. Regression analysis for the SOS strategy.

SOS	B	SE B	Beta	t	Sig
DSFwds	.004	.002	.217	2.34	.021
DSBwds	.003	.002	.182	1.94	.054
Vis Patt span	.002	.002	.080	0.88	.382

5.5.6 Summary of Results

The regression analysis explored the relationship between children's working memory scores and learning to spell using different spelling strategies.

The results suggest that visuospatial short-term memory was a significant predictor of words learned using the Look, Say, Cover, Write, Check (SACAWAC) word-study strategy, although verbal short-term memory was approaching significance level as a predictor ($p = .055$). Visuospatial memory was the only significant predictor of words learned using the General strategy. No firm conclusion can be drawn regarding the principal strategy which the children might have used in the General condition. However, as will be discussed in Chapter 6, there is evidence to suggest that many of the children may have learned the words by writing them out a few times. For words learned using the simultaneous oral spelling strategy (SOS), verbal short-term memory was a significant predictor, although verbal working memory just failed to achieve conventional levels of significance (p = .054).

These results suggest that different study strategies may draw upon different components of working memory. These findings will be explored in Chapter 6 by examining the task demands of each of the strategies.

5.6 ADDITIONAL ANALYSIS

In order to provide a baseline for the results of the training intervention study in Study 2 Part II, the pupils were given a pre-test of the words selected for training. The results showed that despite careful selection of the words to ensure that the children were unlikely to have met them before, some of the pupils were still able to spell a substantial number of these words. The distribution of the pupils' spelling scores on this pre-test is shown in Figure 5. Table 17 shows the mean and standard deviation of the scores.

Table 17. Mean and standard deviation for spelling scores on pre-test

N	Mean	SD
124	10.37	8.75

Based on some evidence in the literature to suggest that the nature of the involvement of working memory components in spelling performance may depend on the level of difficulty of the words (Kreiner, 1992), an additional analysis was carried out to explore whether the same working memory components predicted performance in spelling on this training words pre-test as were found to predict performance in spelling on the standardised test.

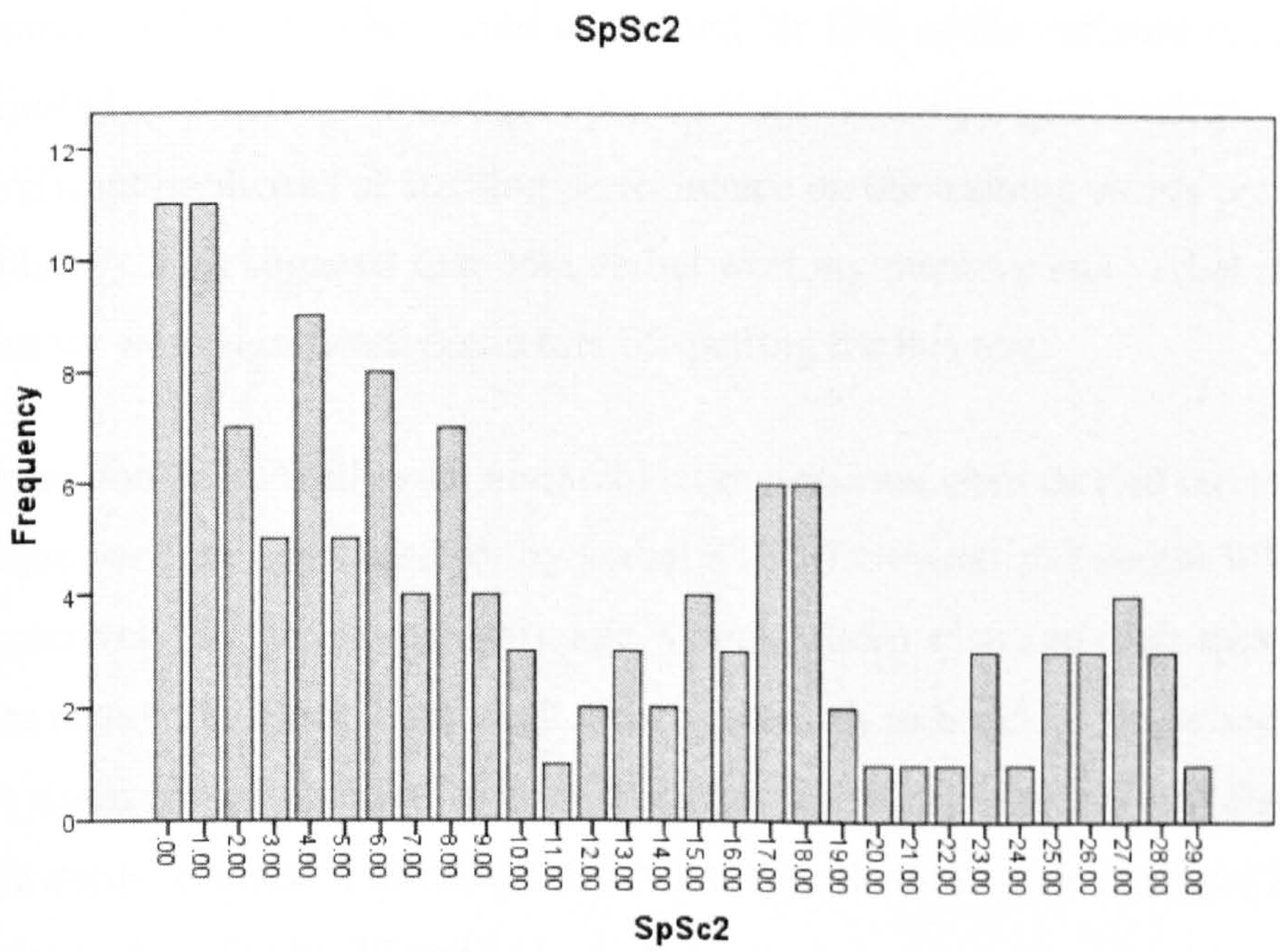

Figure 5. Bar chart showing pupils' spelling scores (SpSc2) on the pre-test of training words.

Regression 3.1 – All three working memory variables were entered simultaneously to examine the variance accounted for by the working memory variables together (see Tables 18 and 19 for regression data information).

Table 18. Model summary for multiple regression of predictors of spelling scores on pre-test

Model	*R*	*R Square*	*Adjusted R Square*	*Std.Err of the Est.*	*F*	*df1*	*df2*	*Sig. F*
1	.40[a]	.16	.13	8.164	5.61	4	119	.000

a. Predictors: (Constant), age, digit span forwards, digit span backwards, visual patt span

Table 19. Simultaneous multiple regression of predictors of spelling scores on training words pre-test

Variable	B	SE B	beta	t	Sig
Chronological age	.095	.198	.041	.48	..633
Digit span forwards	.095	.040	.211	2.39	.019*
Digit span backwards	.117	.045	.236	2.61	.010*
Pattern span	.065	.054	.104	1.19	.236

*p< .05

The results show that a significant model emerged: $F_{4,119)} = 5.61$, $p < .001$ (see model summary Table 18). This model accounted for 13% of the variance of spelling ability (adjusted $R^2 = 0.130$). Both digit span forwards and digit span backwards were significant predictors of spelling performance on the training words pre-test (see Table 19). This suggests that both verbal working memory and verbal short-term memory were significant predictors of spelling for this test.

Regression 3.2: Fixed-order hierarchical regressions were carried out to explore the unique variance accounted for by verbal STM (DSFwds) and verbal WM (DSBwds) respectively. In the first analysis, age, visual pattern span and digit span forwards were entered in Block 1 and digit span backwards in Block 2. In the second analysis, this was repeated with the order of entry for digit span forwards and digit span backwards reversed. The results show that significant models emerged for both analyses (see Tables 20 and 21).

Table 20. Model summary with digit span backwards entered last

Model	R	R square	Adjusted R Square	Std.Err of the Estimate	R Square Change	F Change	df1	df2	Sig. F Change
1	.33[a]	.11	.09	8.361	.11	4.96	3	120	.003
2	.40[b]	.16	.13	8.164	.05	6.86	1	119	.010

a. Predictors: (Constant), pattern span, age mths, digit span forwards
b. Predictors: (Constant), pattern span, age mths, digit span forwards, digit span backwards

Table 21. Model summary with digit span forwards entered last

Model	R	R square	Adjusted R Square	Std.Err of the Estimate	R Square Change	F Change	df1	df2	Sig. F Change
1	.34[a]	.19	.07	8.322	.12	5.37	3	120	.003
2	.40[b]	.16	.13	8.164	.04	5.70	1	119	.019

a. Predictors: (Constant), pattern span, age mths, digit span backwards
b. Predictors: (Constant), pattern span, age mths, digit span backwards, digit span forwards

Tables 22 and 23 provide additional regression information.

Table 22. Hierarchical multiple regression of predictors of spelling scores on the training words pre-test with digit span backwards entered last

Blocks	B	SE B	Beta	t	Sig
Block 1					
Chron age	.036	.202	.015	.18	.860
Vis patt span	.095	.054	.153	1.75	.082
DSFwds	.121	.040	.269	3.07	.003*
Block 2					
Chron Age	.095	.198	.041	.48	.633
Vis patt span	.065	.054	.104	1.19	.236
DSFwds	.095	.040	.211	2.39	.019*
DSBwds	.117	.045	.236	2.62	.010*

*$p < .05$

Table 23. Hierarchical multiple regression of predictors of spelling scores on the training words pre-test with digit span forwards entered last.

Blocks	B	SE B	Beta	t	Sig
Block 1					
Chron age	.091	.202	.039	.45	.860
Vis patt span	.079	.055	.128	1.44	.082
DSBwds	.143	.044	.290	3.26	.003*
Block 2					
Chron Age	.095	.198	.041	.48	.633
Vis patt span	.065	.054	.104	1.19	.236
DSBwds	.117	.045	.236	2.62	.010*
DSFwds	.095	.040	.211	2.39	.019*

*$p < .05$

Table 22 shows that when digit span backwards was entered in Block 2 after controlling for the other independent variables, it was a significant predictor (t = 2.62, $p = .01$). The model summary (Table 20) shows that it accounted for an additional variance of 5% (R^2 change = 0.05) beyond the contribution of the other variables.

Table 23 shows that for the order reversed with digit span forwards entered in Block 2, it was also a significant predictor (t = 2.39, p = .019) accounting for an additional variance of 4% (R^2 change = 0.04 –see Table 21).

5.6.1 Summary of results

The results showed that both verbal short-term and verbal working memory predicted spelling performance on the pre-test of training words, accounting for 4% and 5% of the variance respectively. This is in contrast to the result of the analysis of performance on the age-appropriate standardised spelling test, which showed that only verbal short term memory was a significant predictor accounting for an additional 7% of the variance.

The finding that verbal working memory as well as verbal short-term memory significantly predicted spelling performance in the training words pre-test could reflect the information processing demands of this task. Most of the children did not know how to spell these words and therefore they may have drawn upon different strategies for spelling which could have taxed working memory resources. However, given that the scores obtained overall were low, the result could be partly due to a floor effect.

CHAPTER 6. DISCUSSION

6.1 RESEARCH QUESTIONS AND FINDINGS

The main aim of this research was to investigate the role played by working memory in supporting children in learning to spell. Three research questions were explored.

1. What is the relationship between working memory and spelling ability?
2. Do multisensory spelling strategies assist children in learning to spell?
3. How adequately can the Baddeley and Hitch multi-component model account for performance in learning to spell using such strategies?

Research Question One

1. What is the relationship between working memory and spelling ability?

Study 1 investigated the relationship between working memory and spelling by conducting a series of regression analyses to explore the contribution of different components of working memory to spelling performance. The results showed that only recall of digits forwards was a significant predictor of spelling, accounting for 7% of unique variance. This suggests that verbal short-term memory may be an important underlying factor in the development of spelling skills.

There is some support in the literature for the importance of verbal short-term memory in spelling from early studies by McLeod and Greenough (1980) and Ormrod (1986) which reported that poor spellers have shorter verbal short-term memory spans than good spellers (but see Savage and Frederickson, 2006). Research studies have also examined the predictive nature of working memory components in spelling ability. However, as most of these studies have included additional phonological factors in the analysis, such as phonological awareness and rapid automatic naming, it is difficult to draw comparisons with results reported here. A consistent finding from these studies has been that working memory is not a significant predictor of spelling once the contribution of other phonological factors is taken into account (e.g. Cornwall, 1992; McCallum et al., 2006; Pennington et al., 2001; Savage et al., 2005; Scarborough, 1998). This is likely to be due to the shared variance between the factors, as shown by the statistically significant correlations amongst the phonological processing variables reported in most of these studies.

There is evidence to show that when working memory is examined as a single independent phonological variable, it does contribute significant variance to spelling. However, the picture is not clear. Ormrod and Cochran (1988) examined working memory and spelling in college students. The results provided evidence of a significant contribution of verbal working memory to the spelling performance of college students. Verbal short-term memory was not assessed in this study. Cormier and Dea (1997) examined the influence of both working memory and phonological awareness on spelling ability. This study reported that a (composite) verbal memory factor accounted for a significant amount of variance (4.6 %.) in spelling when entered into a regression equation before phonological awareness. However, the memory factor used in this study was a composite measure. Therefore, it is not possible to say to what extent either verbal short-term or working memory might have contributed to the result. A study by Tijms (2004), reported that a verbal memory factor accounted for a unique 2% of significant variance in spelling beyond the contribution of phonological awareness. However, the verbal memory factor used here was a composite measure which additionally included a verbal learning task. Therefore it is not possible to say to what extent either verbal short-term or working memory, or a learning factor, contributed to the results. In addition, the overall results of this study could reflect the greater transparency of the Dutch language compared to English as discussed earlier in Chapter 2.

The study by Savage et al. (2005) appears to be the only published study to have reported a unique effect of verbal short-term memory on spelling when controlling for other phonological processing variables. The effect was found only for poor spellers. This study reported that verbal ST memory but not verbal WM added unique power to the discrimination of below-average and average spellers beyond the contribution of RAN and phonological awareness. However, it was not found to discriminate between average and above-average spellers. A regression analysis confirmed the specificity of the effect of verbal short-term memory. The analysis showed that verbal short-term memory did not account for any additional variance in spelling once the whole sample was taken into account. However, verbal working memory did account for an additional 2% of the variance, although this was not significant (Savage, 13.06.08, personal communication).

In conclusion, there has been considerable debate in the literature about the extent to which working memory and other phonological processes, particularly phonological awareness, might tap into the same underlying abilities. The interactive nature of these processes therefore makes it difficult to isolate their unique contribution to the development of literacy skills. The research carried out here does not add any new empirical evidence in this respect. However, the findings of the research, together with the evidence from existing studies, points to a key role for verbal memory, and verbal short-term memory in particular, in learning to spell.

Effect of word difficulty

One factor which may affect the results of studies investigating working memory and spelling, and which to the writer's knowledge has not been previously explored in the literature, is the effect of word difficulty. The study by Kreiner (1992) was designed to test predictions about the dual-route model of spelling and involved college undergraduate students who were said to be skilled spellers. The results showed that verbal working memory but not short-term memory was significantly correlated with word difficulty. Kreiner argued that this result suggested that working memory is important in skilled spelling.

The present study provides some additional though by no means conclusive evidence that the contribution of working memory to spelling performance may depend on the processing demands of the task. This comes from the additional analysis which was carried out to explore the contribution of working memory to spelling performance using the spelling scores on the pre-intervention training words as the dependent variable. This analysis showed that both verbal short-term and verbal working memory were significant predictors of spelling performance, accounting for 4% and 5% of unique variance respectively. This is in contrast to the analysis using the standardised age-normed spelling test as the dependent variable, which found that only verbal short-term memory was a significant predictor of spelling.

A possible explanation for this result could come from a consideration of information processing demands. As most of the words for training were unknown to the children, they are unlikely to have been spelled using a purely lexical route. It is likely that the children may have drawn on a range of strategies and word-specific information to help spell the words. One way might have been to use a phonological route, mapping sounds onto letters. This could have been be supported by knowledge of spelling patterns and orthographic and morphological principles (e.g. Templeton and Bear, 1992). Another way of spelling the word could have been by analogy (Goswami, 1988). This would involve searching in long-term memory for a word or part of a word with a similar onset or rime. Decisions would then have to be made concerning adaptations to the word to form the target word. There may also have been partial knowledge of how the word was spelled, with the rest of the word being made up by drawing on a range of different sources of knowledge available to the speller. Some or all of these strategies are likely to have drawn on executive functions such as task switching (from lexical to sublexical spelling routes), inhibition (of conflicting spelling information), and updating (comparing, checking and amending) thus drawing on central executive resources.

In summary, the results of this additional analysis provide some evidence to suggest that the contribution of working memory to spelling performance may depend in part on the complexity of the spelling task presented. However, this evidence is not conclusive. Although some of the training words were spelled correctly by the pupils at pre-test, most of them were not, suggesting a floor effect.

Research Question Two

2. Do multisensory spelling strategies assist children in learning to spell?

Study 2 (Part I) explored the effectiveness of different multisensory spelling strategies in helping children learn new spelling words. The two multisensory strategies used were a 'look-say-cover-write-check' procedure in condition two, and a 'simultaneous oral spelling' procedure in condition three. In condition one, the 'General' condition, the pupils were instructed to learn the words using any strategy they might normally use.

The results of the intervention showed that all of the training conditions resulted in the children knowing significantly more words at post-test than pre-test and this effect was maintained after three weeks. No one condition was more effective than any other. There was a trend for fewer words to be learned and maintained using the SOS strategy although these effects were not significant.

When considering how these results compare with the spelling intervention studies reviewed in Chapter 1, direct comparisons are difficult. Most of the studies reviewed in Chapter I involved children with learning difficulties, and those interventions which did use typically developing children did not examine the same strategies as were examined here, and reported on strategies such as error-correction (e.g. Harward et al., 2004; Gettinger, 1993), distributed practice (Guza and McLaughlin, 1987) or a comparison of motoric conditions such as writing and the computer (e.g. Cunningham and Stanovitch, 1990; Vaughn et al., 1993). However, the findings of the training study carried out in this thesis do provide some support for the research showing the efficacy of the SOS method in helping children learn to spell (Bradley, 1981; Hulme and Bradley, 1984; Thomson, 1988, 1991) in that the results reported here also suggest that this is an effective strategy. That it was actually no more effective than any other for this group of children is also consistent with previous research. Hulme and Bradley (1984) and Cunningham and Stanovitch (1990) provided evidence to show that whilst writing was a critical component in learning to spell for average readers and spellers, the effect was not enhanced by letter naming (see also Thompson, 1991). Hulme and Bradley (1984) argue that children's problems with reading and spelling may arise from their difficulties in segmenting speech sounds and the subsequent coding of these sounds in verbal memory. However, normal readers and spellers who do not have these difficulties may feel that naming each letter in the word is an 'irrelevant activity' which does not help them learn to spell the word (Hulme and Bradley, 1984, p. 441).

It is necessary at this point to make some comments on condition one. The rationale for condition one arose from research which has suggested that many pupils with learning difficulties find it hard to learn new spelling words independently because they lack systematic word study strategies. However, if the same students are specifically taught a spelling strategy, they are able to apply this effectively in learning to spell (e.g. Fulk, 1996; Graham and Freeman, 1985). It had initially been intended to use condition one as a control or comparison to find out if the children learned more effectively when they had been directly taught a strategy to use. However, in practice this turned out to be problematic for a number of reasons. First, the results showed that all three conditions were more or less equally effective. This is likely to be because the studies by Fulk (1996) and Graham and Freeman (1985) noted above involved children with learning difficulties. The children in the present study were all typically developing children, and it is probable that many were already able to apply learning strategies independently and effectively in private study.

A second reason why it proved difficult to use condition one as a comparison was that it was not possible to say with any certainty which strategy or strategies the pupils adopted in condition one. Later discussions with class teachers suggested that most of the children chose to write the word down a number of times and silently study the word. Some support for this comes from an examination of the pupils' practice papers, at least with respect to writing the word. It is also possible that pupils may have been 'primed' by initial teacher instruction. An examination of teacher scripts for condition one showed that the pupils were told they could learn the words any way they chose but also that they could *'use the space beneath the words to copy the letters out'* if they wished. However, none of this evidence is conclusive and condition one remains underspecified.

In summary, all three spelling conditions in the training intervention study resulted in the children knowing more words at post-intervention compared with pre-intervention. No one spelling strategy proved to be significantly better than any other. The results support previous research which suggests that for typically developing children, a range of spelling strategies may be effective. The results also support studies which have suggested that although saying the letter name out loud as it is written can help children who are struggling spellers, it appears to have no additional effect for typically developing spellers.

Research Question Three

Study 2 (Part II) explored the extent to which the Baddeley and Hitch multi-component model could account for performance in learning to spell using different multisensory strategies. A series of regression analyses was carried out to examine relationships between the numbers of words learned in each condition and pupils' working memory scores. G-ratios (McGuigan, 1978) were used as an index of number of words learned.

To recap, words were learned under three different conditions: a 'look, say, cover, write, check' (SACAWAC) condition, a simultaneous oral spelling strategy (SOS) condition, and a General condition. For the remainder of this discussion, it is assumed that the main strategy the pupils adopted in the General condition was to repeatedly copy the words out, with the caveats noted in the previous section.

The results showed that spelling scores following training in each of the separate conditions were predicted by different components of the working memory system. This suggests that the different spelling strategies may have drawn on different components of working memory. These results might be explained by considering the task demands of each of the strategies.

All of the strategies involve writing. However, the SACAWAC method encourages visual analysis with its emphasises on looking and checking. There is also a phonological element as the word is spoken out loud. The SOS method encourages phonological analysis as the word is broken down into individual letters and each letter is sounded out as it is written. The copying strategy draws on visual and motor skills for looking and writing.

The result of the regression analysis for the SACAWAC strategy found that visual pattern span was a significant predictor, although digit span forwards was approaching significance ($p = .054$). This suggests that the SACAWAC strategy draws on resources from the visuospatial sketchpad and to a lesser extent the phonological loop, supporting the suggested emphasis on visual analysis.

For the 'SOS' strategy, digit span forwards was a significant predictor of spelling, with digit span backwards approaching significance. Visual pattern span was not found to be a significant predictor. This suggests that the main predictor of spelling was the phonological loop, which supports the emphasis on phonology. The results suggest that verbal working memory may also have been involved albeit to a lesser extent. A tentative explanation could be put forward for this based on the processing demands of this strategy. The strategy involves the explicit segmentation of a word into its constituent phonemes. The speller would also have to coordinate the articulation of each letter name with the writing of the letter, as well as keeping serial order. These steps may have required resources from the central executive. There is also the fact that for most of the children this was a totally new strategy, and as Dehn (2008) suggests, using an unfamiliar strategy may place its own demands on central executive resources. Two teachers also reported that the children found the SOS strategy the most difficult strategy to use. One teacher commented that the children in her class felt 'uncomfortable' with the SOS strategy as they were used to working quietly and didn't like to say the letter name out loud.

This result appears to support the suggestion by Bradley (1981) that the SOS strategy assists auditory analysis. However, the visual/spatial component which would be emphasised through writing and linking the motor pattern with the sound of the word did not appear to be significant for this group of children. However, this could have been due to the age of the children and also the fact that the large majority did not have spelling difficulties. For this group of children, writing is likely to have already become reasonably automatic. However, the more unfamiliar component, which saying each letter name out loud as the word was written, was the process which demanded most attention with a resulting the focus on the phonological loop.

The results of the regression analysis for spelling using the General (copying) strategy show that only visual pattern span was a significant predictor of spelling, suggesting a reliance on the visuospatial sketchpad. This supports the use of visual and motor skills when copying.

In summary, this study has shown that different spelling strategies make different demands on working memory which can be accounted for using the Baddeley and Hitch model of working memory. This was demonstrated by using regression analysis to explore the extent to which working memory components, as measured by working memory tasks developed from the Baddeley and Hitch model, predicted spelling performance following learning to spell using different spelling strategies. The results suggested that the more visual the strategy, the more demands made on the visuospatial sketchpad. The more emphasis which is placed on auditory steps such as saying words and letters out loud, the greater the demands on the phonological loop. Finally, strategies which are unfamiliar and/or which may require the coordination of different steps may require additional processing resources thus drawing on the central executive of working memory.

6.2 LIMITATIONS OF THE PRESENT STUDY

The first limitation of this study concerns the spelling test chosen as the independent variable in Study 1. Study 1 explored the relationship between working memory and spelling using regression analyses to examine the contribution of different components of working memory to spelling performance. However, the spelling test which was chosen as the dependent variable may have been too easy for the children. Because the test was to be administered in the first term of Primary Five, the test manual recommend the use of an earlier stage test, which was selected. This created two problems. First, standardised scores were not available for some of the older children. To compensate for this, age was included as an independent variable in the regression analysis. The second problem was that the spelling scores showed signs of significant negative skew. However, as discussed in section 5.3.6, a square root transformation and subsequent analysis using the transformed data showed this did not seem to have affected the overall results.

A second possible limitation of this research was the use of the G-ratio in Study 2 Part II as an index for new words learned in training. This index does not allow a value to be calculated for children who scored full marks, as this would result in a denominator of zero. However, data from only five pupils was affected.

A third limitation was that only single measures were used for each working memory component. The use of composite scores from more than one task would have increased the reliability of the measure as the result would have been less likely to have been affected by task-specific variance. In addition, no test-retest reliability coefficient was available for the visual patterns test. This is a test designed for adults which has been adapted and standardised for children by the authors of the Working Memory Test Battery for Children (Pickering and Gathercole, 2001). Its status at the moment is uncertain.

Finally, the 'General' spelling condition did not allow for any control or comparison to be made. With hindsight, more information may have been gathered had this condition been more specified. For example, a 'copy only strategy' could have been implemented as the first condition, which would also have allowed the conditions to continue to be run consecutively as each strategy was building on the previous one

6.3 SUGGESTIONS FOR FURTHER RESEARCH

This study found that all the multisensory strategies used were equally effective in helping the children to learn new words. This is consistent with the research literature which suggests that children whose spelling skills are developing along expected pathways may obtain equal benefit from a number of different spelling strategies (e.g. Brooks and Weeks, 1998; Guza and Mclaughlin,1987; Hulme and Bradley, 1984). Further research using a large-scale study continuing a sizeable proportion of children with spelling difficulties would be helpful to find out more about the possibility of children's differential responses to spelling strategies. This would also allow a more detailed analysis to explore if children's responses to different strategies depended on their cognitive or working memory profiles. It would also be helpful to explore other factors that might constrain or support the effects of multisensory strategies on spelling, such as developmental stage, or extent of the spelling difficulty. It would also be interesting to explore relationships between episodic buffer functioning and learning to spell using multisensory strategies, although as yet here are no well-developed tests to measure episodic buffer functioning. The possibility of a dual-coding conflict in children with literacy difficulties, as noted by Palmer (2000b), would also be an interesting issue to explore further.

Finally, the specific RAN-spelling associations identified by Savage et al. (2008) and possible implications for spelling development would benefit form further research.

6.4 IMPLICATIONS FOR SPELLING PRACTICE

In making recommendations for spelling practice, it may first be helpful to consider what the research suggests are the critical factors in learning to spell. As discussed in Chapter 2, there is abundant evidence to show that phonological awareness is a key cognitive ability underlying the development of literacy skills. Research has also suggested that one of the most important aspects of this ability in relation to spelling is the ability to segment words into phonemes (Burns and Richgels, 1989; Cataldo and Ellis, 1988; Ellis and Cataldo, 1990; Read, 1975). The importance of letter knowledge for the development of spelling has also been clearly demonstrated (e.g. Bruck, Genesee and Caravolas, 1997; Byrne and Fielding-Barnsley, 1989). Other studies have shown that the combined influence of these factors is greater than if their effects were considered independently (Muter et al 1998; Caravolas et al., 2001). Results of training studies have also consistently demonstrated that training in phoneme segmentation skills and instruction in letter sound knowledge significantly improves children's spelling skills (e.g. Ball and Blachman, 1991; Foorman et al., 1991; Castiglioni-Spalten and Ehri, 2003; Lundberg et al., 1988; Bradley and Bryant, 1983, 1985; Ehri and Wilce, 1987; Uhry and Shepherd, 1993). This would suggest that for children whose phonological skills may be weak, early intervention training may be crucial.

Recommendation 1. Training in phonological awareness which includes phonological segmentation, in combination with direct and systematic instruction in letter-sound knowledge, should be a key component of teaching programmes at the very earliest stages of beginning to learn to spell. Early identification of children whose phonological skills are weak is important to allow them to benefit from more intensive and focused input.

Study 1 found that when working memory was investigated as a single independent variable, verbal short-term memory was a significant predictor of spelling. Although the precise role of working memory in spelling is not completely clear, it is likely that verbal short-term memory may help to establish strong phonological representations through phonological coding (e.g. Brady, 1997). However, previous research has suggested that children with literacy difficulties may place a much greater reliance on visual memory and orthographic coding than on phonological coding when reading and spelling (e.g. Hulme, 1981; Lennox and Siegel, 1998; Palmer, 200b; Stuart et al., 2000; Rack, 1985) although the precise meanings of these terms in relation to words is not often made clear in the literature.

As discussed previously in Chapter 3, it is not surprising that if children's phonological coding skills are compromised then they may draw on other working memory processes to support their learning, such as their visual memory. However, it has been shown that this is not the optimal strategy for the development of effective literacy skills (Palmer, 2000b; Stuart et al., 2000). Stuart (2000) has suggested that visual memory may be the 'strategy of last resort' for those who have no other strategy available (p. 18).

The fundamental question, therefore, is how best to support children who have phonological difficulties and who may possibly place an over-reliance on visual strategies when reading and spelling. There appears to be no straightforward answer to this question. However, a crucial factor may be the extent to which reading and spelling are interactive. Exactly how spelling might support reading and vice versa is not completely understood (e.g. Ehri, 1997; see also Caravolas et al., 2001). Firth's (1985) interactive model of reading and spelling proposes that the stages in reading and spelling development, that is, logographic, alphabetic, and orthographic (see Chapter 2), may develop out of step with each other, but interact with a corresponding mutual influence on each other. Frith suggests that when children first begin to read they adopt a visual strategy. They then move on to a more phonological strategy i.e. logographic to alphabetic (see also Ellis, 1997; but see Goswami and Bryant, 1990). Frith (1980) also suggests that children who are 'unexpectedly poor spellers' may use a visual strategy for reading which relies on only 'partial cues', for example 'first letter and overall length (Frith, 1980, p. 507). This approach means that children pay less attention to the whole word and may therefore have less opportunity to develop the skills required to move on to the alphabetic stage in reading.

Ehri (1987, 1997) suggests that children first begin to understand the alphabetic principle through practice in spelling, and that it is this understanding that helps them make the shift from a logographic to an alphabetic strategy in reading. Ehri suggests that 'teaching students to read without also teaching them to spell may result in reading and spelling skills that are less closely related' (Ehri, 1997, p. 265), which may lead to an over-reliance on visual skills. This may have significant implications for the successful development of both reading and spelling skills in all children, but particularly in children who have phonological difficulties to begin with. Therefore, it may be that to encourage the use of phonological strategies in literacy and to benefit from the mutually interactive effect that spelling and reading have on each other, a greater emphasis needs to be placed on spelling in the very beginning stages of learning to read and spell.

Recommendation 2: Children should be provided with as many opportunities to learn and practice spelling as are provided for reading, particularly in the very early stages of development. This may not only help to lay the necessary foundation of alphabetic knowledge but may also take optimum advantage of the interactive nature of reading and spelling and encourage each one to grow from the other.

The above discussion focuses on the development of phonological strategies to help build up children's spelling skills. However, this does not imply that the use of visual memory to support spelling should be discouraged. On the contrary, visual memory has been acknowledged to be an important factor in helping to learn the large number of irregular spelling patterns that exist in the English language (Ehri, 1997, Ehri and Wilce, 1987). Therefore, just as reading and spelling develop in interaction with each other, so too may visual and phonological pathways interact when learning to spell. This suggests that children should be taught to use a range of different strategies for spelling, including multisensory strategies which may encourage the use of a range of working memory pathways to support spelling. Part II of Study 2 found that different spelling strategies may place a different emphasis of components of working memory. The results suggested that a *Look, Say, Cover, Write, Check* strategy emphasised visual memory, whilst also drawing on verbal short-term memory albeit to a lesser albeit. The SOS strategy appeared to place more reliance on the phonological loop of working memory emphasising a more phonological approach, at least for this group of children.

The relative effectiveness of any one strategy may depend upon factors such as the age and developmental spelling stage of children as well as their strengths and weaknesses. Phonological strategies may be particularly important in the early stages of spelling (e.g. Cataldo and Ellis, 1988, Goswami and Bryant, 1990). In the transitional stage, children may rely more on visual memory for word patterns (e.g. Ehri, 1997; Ellis 1997; Frith, 1985). Children with phonological difficulties might be supported using a strategy such as simultaneous oral spelling, as this may encourage and help to strengthen skills in phoneme segmentation (Bradley, 1981; Hulme and Bradley, 1984; Thomson, 1988, 1991). This could be supplemented with a visual approach which may draw on visual memory to help strengthen the connection between the visual and auditory elements of words, such as the *Look, Say, Cover, Write, Check* Strategy, for which there is strong empirical support (e.g. Fulk, 1996; Graham and Freeman, 1985; Murphy et al., 1990; Nies et al., 2006). This type of strategy might also be very helpful for children who have significant phonological weaknesses as part of wider programme of teaching word analysis skills (see the following section). For children without spelling difficulties, the use of a range of different spelling strategies could help to optimise the use of the many different sources of knowledge which children have been shown to draw upon when learning to spell. For children with spelling problems, appropriate assessment of the nature of their difficulties would be essential before considering the forms of support that might be helpful.

Recommendation 3: The development of both phonological and visual strategies in children should be encouraged through the use of appropriate spelling strategies. This is not only to draw on all possible sources of knowledge that can help to support the development of spelling, but also to help further strengthen the connection between the sounds in words and their visual features, leading to a greater understanding of the alphabetic principle. For children with spelling difficulties, phonological strategies may be particularly important to help develop segmentation skills and alphabetic knowledge. However, children should also be encouraged to use visual as well as auditory approaches to help develop orthographic knowledge and make connections between auditory and visual aspects of words. In all cases, appropriate assessment is crucial in order to identify the needs of any particular children with difficulties.

As has been discussed in previous chapters, children are active learners drawing on a range of different sources of knowledge about spelling from an early stage and the degree to which they utilise these knowledge sources also varies across time (e.g. Rittle-Johnson and Siegler, 1999; Treiman and Bourassa, 2000; Varnhagen et al., 1997). There is also now a growing awareness of the importance of knowledge of orthographic principles and spelling rules for the development of proficient spelling, particularly in relation to the morphological structure of words (e.g. Nunes et al., 2003), and that children begin to apply this knowledge earlier than was once first thought (Treiman et al., 1994). Research has also shown that although some children can acquire this knowledge through reading and experience with print, most children need to be explicitly taught (e.g. Chliounaki and Bryant, 2007).

Children with phonological weaknesses may also find it less demanding to process parts or 'chunks' of graphemic information, such as rime units or commonly occurring letter strings, rather than individual graphemes. If this is the case then spelling activities which build up knowledge of orthographic patterns in words and which teach rules based in orthographic and morphological principles may be helpful. Such strategies may reduce memory demands, particularly demands on phonological memory. It is important to emphasise here that these strategies are likely to be of benefit to *all* children, not just those with phonological weaknesses. Developing children's skills in working with parts of words may make it easier for them to access these parts directly by spelling through a lexical spelling route. In addition, as discussed in the conceptual framework in Chapter 5, increasing domain knowledge such as knowledge of spelling rules and morphemic structure may increase the number of possible associations that could be made for the word in LTM. This could help to establish a more durable representation in LTM as well as making it easier to access the word at retrieval.

Examples of spelling activities which help children learn about patterns in words and for which there is empirical support in the literature include spelling by analogy (e.g. Englert et al., 1985; Goswami, 1988; Nation and Hulme, 1998), building up words using onsets and rimes (e.g. Frederickson and Wilson, 1996), and applying morphological rules when spelling (e.g. Arnbak and Elbro, 2000; Darch et al., 2000; Nunes et al., 2003). It should also be noted that in the review of spelling interventions carried out in Chapter 1, the intervention which resulted in the highest effect size (ES = 1.76) was the study by Darch et al. (2000) which was an intervention focusing on rules using phonemic and morphemic strategies.

Recommendation 4. Children should be given lots of opportunities to practise building up words using onsets and rimes and to practise spelling by analogy. For children with spelling difficulties, systematic instruction using such methods should be considered.

Recommendation 5. A greater emphasis should be placed on teaching about morphemes within the general spelling instructional programmes in schools. For children with spelling difficulties, specific training in morphological awareness should be incorporated within intervention spelling intervention packages.

Finally, research shows that teachers lack confidence in their knowledge and understanding of many aspects of spelling theory and instruction (Fresch, 2007;

Johnston, 2001). This appears to be particularly true of teachers' understanding of complex spelling rules and morphological principles (Hurry et al., 2005).

Recommendation 6. Spelling theory and instruction should be an essential part of all teacher-training courses. Local Authorities should issue comprehensive guidelines regarding the teaching of spelling within a wider framework of literacy development. Schools should have explicit and detailed polices for teaching spelling.

REFERENCES:

Ackerman, P.T., and Dykman, R.A. (1993). Phonological processes, confrontation naming, and immediate memory in dyslexia. *Journal of Learning Disabilities, 26(9),* 597–690.

Ackerman, P.T., Holloway, C.A., Youngdahl, P.L., and Dykman, R.A. (2001). The double-deficit theory of reading disability does not fit all. *Learning Disabilities Research and Practice, 16(3),* 152-160.

Adams, M.J. (1990). *Beginning to read-thinking and learning about print.* Cambridge, MA: Mit press.

Alber, S., and Walshe, S.E. (2004). When to Self-Correct Spelling Words: A Systematic Replication. *Journal of Behavioral Education, 13(1),* 51-66.

Allen, R.J., Baddeley, A.D., and Hitch, G.J. (2006). Is the binding of features in visual working memory resource-demanding? *Journal of Experimental Psychology: General, 135(2),* 298-313.

Alloway, (2007). *Automated Working Memory Assessment* (AWMA). London: Pearson.

Alloway, T.P., and Gathercole, S.E. (2005). The role of sentence recall in reading and language skills of children with learning difficulties. *Learning and Individual Differences, 15(4),* 271–282.

Alloway, T.P., Gathercole, S.E., and Pickering, S.J. (2006). Verbal and visuo-spatial short-term and working memory in children: Are they separable? *Child Development, 77(6),* 1698-1716.

Alloway, T.P., Gathercole, S.E., Adams, A-M., and Willis, C. (2005). Working memory abilities in children with special educational needs. *Educational and Child Psychology, 22(4),* 56-67.

Alloway, T. P., Gathercole, S. E., Willis, C. S., and Adams, A.-M. (2004). A structural analysis of working memory and related cognitive skills in young children. *Journal of Experimental Child Psychology, 87(2),* 85-106.

Alvarez, J. A., and Emory, E. (2006). Executive Function and the Frontal Lobes: A Meta-Analytic Review. *Neuropsychology Review, 16(1),* 17-42.

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

Annett, M. (1998). Handedness and cerebral dominance: The right shift theory. *Journal of Neuropsychiatry, 10(4),* 459–469.

Arnbak, E., and Elbro, C. (2000). The Effects of Morphological Awareness Training on the Reading and Spelling Skills of Young Dyslexics. *Scandinavian Journal of Educational Research, 44(3),* 229-252.

Atkinson, R. C., and Shiffrin, R. M. (1968). Human memory: A proposed system and its control processes. In K. W. Spence and J. T. Spence (Eds.) *The psychology of learning and motivation: Advances in research and theory. (Vol. II pp.89-195).* New York: Academic Press.

Baddeley, A. D. (1966). Short-term memory for word sequences as a function of acoustic, semantic and formal similarity. *Quarterly Journal of Experimental Psychology, 18(4),* 362-365.

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

Baddeley, A. D. (1996a). Exploring the central executive. *Quarterly Journal of Experimental Psychology: A, 49(1),* 5–28.

Baddeley, A. D. (1996b). The fractionation of working memory. *Proceedings of the National Academy of Sciences, 93(24),* 13468-13472.

Baddeley, A. D. (1997). *Human Memory: Theory and Practice.* Hove, England: Psychology Press.

Baddeley, A. D. (1998). The central executive: A concept and some misconceptions. *Journal of the International Neuropsychological Society, 4(5),* 523–526.

Baddeley, A.D. (2000). The episodic buffer: A new component of working memory? *Trends in Cognitive Sciences, 4(11),* 417-423.

Baddeley, A.D. (2002). Is working memory still working? *European Psychologist, 7(2),* 85-97.

Baddeley, A. D. (2003). Working memory and language: An overview. *Journal of Communication Disorders, 36(3),* 189-208.

Baddeley, A.D. (2007). *Working memory, thought, and action.* Oxford: Oxford University Press.

Baddeley. A.D., and Allen, R.J. (2009). Working memory and sentence recall. In A. Thorn and M Page (Eds.), *Interactions between short-term and long-term memory in the verbal domain (pp. 63-85).* Hove, East Sussex, UK: Psychology Press.

Baddeley, A.D., and Antrade, J. (2000). Working memory and the vividness of imagery. *Journal of Experimental Psychology: General, 129(1),* 126-145.

Baddeley, A.D. and Hitch, G. (1974). Working memory. In G.H.Bower, (Ed.), *Recent Advances in Learning and Motivation (Vol. 8, pp47-90).* New York: Academic Press.

Baddeley, A. D., and Hitch, G. J. (1994). Developments in the concept of working memory. *Neuropsychology, 8(4),* 485-493.

Baddeley, A.D., and Hitch, G. (2007). Working memory: past, present...and future? In N. Osaka, R.H. Logie, and M. D'Esposito (Eds.), *The cognitive neuroscience of working memory (pp.1-20).* Oxford: Oxford University Press.

Baddeley, A.D., and Levy, B.A. (1971). Semantic coding and short-term memory. *Journal of Experimental psychology, 89(1),* 132-136.

Baddeley, A. D., and Logie, R. H. (1999). Working memory: The multi-component model. In A. Miyake and P. Shah (Eds.), *Models of working memory: Mechanisms of active maintenance and executive control (pp. 28-61).* Cambridge, UK: Cambridge University Press.

Baddeley, A. D., Gathercole, S. E., and Papagno, C. (1998). The phonological loop as a language learning device. *Psychological Review, 105(1),* 158-173.

Baddeley, A.D., Lewis, V.J., and Vallar, G. (1984). Exploring the articulatory loop. *Quarterly Journal of Experimental Psychology, 36(2),* 233-252.

Baddeley, A. D., Papagno, C., and Vallar, G. (1988). When long term learning depends on short-term storage. *Journal of Memory and Language, 27(5),* 586-595.

Baddeley, A. D., Thompson, N., and Buchanan, M. (1975). Word length and the structure of short-term memory. *Journal of Verbal Learning and Verbal Behavior, 14(6),* 575-589.

Baddeley, A. D., Vallar, G., and Wilson, B. A. (1987). Sentence comprehension and phonological memory: Some neuropsychological evidence. In M. Coltheart (Ed.), *Attention and performance vol. XII: The psychology of reading (pp. 509-529).* Hove, England: Erlbaum.

Baddeley, A.D., Emslie, H., Kolodny, J., and Duncan, J. (1998) Random generation and the executive control of working memory. Quarterly Journal of Experimental Psychology: A, 51(4), 819–852.

Baddeley, A., Cocchini, G., Della Sala, S., Logie, R. H., and Spinnler, H. (1999). Working memory and vigilance: evidence from normal aging and Alzheimer's disease. *Brain and Cognition, 41(1),* 87-108.

Badecker, W., Hillis, A., and Caramazza, A. (1990). Lexical Morphology and its Role in the Writing Process: Evidence from a Case of Acquired Dysgraphia. *Cognition, 35(3),* 205-243.

Badian, N.A. (1993). Phonemic awareness, naming, visual symbol processing, and reading. *Reading and Writing, 5(1),* 87–100.

Ball, E. W., and Blachman, B. A. (1991). Does phoneme awareness training in kindergarten make a difference in early word recognition and developmental spelling? *Reading Research Quarterly, 26(1), 49-66.*

Barron, R. W., and Baron, J. (1977). How Children Get Meaning from Printed Words. *Child Development, 48(2),* 587-594.

Barrouillet, P., and Camos, V. (2001). Developmental increase in working memory span: Resource sharing or temporal decay? *Journal of Memory and Language, 45(1),* 1–20.

Barrouillet, P., Bernardin, S., and Camos, V. (2004). Time constraints and resource sharing in adults working memory spans. *Journal of Experimental Psychology: General, 133(1),* 83-100.

Barrouillet, P., Bernardin, S., Portrat, S., Vergauwe, E., and Camos, V. (2007). Time and cognitive load in working memory. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 33(3),* 570–585.

Barry, C. (1994). Spelling routes (or roots or rutes). In G.D.A. Brown and N.C. Ellis (Eds.), *Handbook of spelling: Theory, process and intervention (pp. 27-49).* Chichester, England: John Wiley and Sons.

Barry, C., and Seymour, P.H.K. (1988). Lexical priming and sound-to-spelling contingency effects in nonword spelling. *The Quarterly Journal of Experimental Psychology: A, 40(1),* 5- 40.

Basic Skills Agency, (2003). *Basic Skills, March, p.9.* Available at: http://www.basic-skills.co.uk/content/documents/?FileID=1916104495

Bayliss, D. M., Jarrold, C., Gunn, M. D., and Baddeley, A. D. (2003). The complexities of complex span: Explaining individual differences in working memory in children and adults. *Journal of Experimental Psychology: General, 132(1),* 71–92.

Bayliss, D. M., Jarrold, C., Baddeley, A. D., Gunn, D. M., and Leigh, E. (2005). Mapping the developmental constraints on working memory span performance. *Developmental Psychology, 41(4),* 579 – 597.

BBC News 24, (2007a). *Job applications 'full of errors',* 3 January. Available at: http://news.bbc.co.uk/1/hi/business/6226439.stm

BBC News 24. (2007b). *Poor basic skills 'costing firms',* 20 February. Available at: http://news.bbc.co.uk/1/hi/education/6376533.stm

BBC News 24. (2007c). *Army has 'poor literacy levels'*, 5 May. Available at: http://news.bbc.co.uk/1/hi/uk/6418683.stm

Bean, W., and Bouffler, C. (1987). *Spell by writing*. Portsmouth, NH: Heinemann.

Bear, D.R., and Templeton, S. (1998). Explorations in developmental spelling: Foundations for learning and teaching phonics, spelling and vocabulary. *Reading Teacher, 52(3),* 222-242.

Beaton, A.A. (2004). The neurobiology of dyslexia. In M. Turner and J. Rack, (Eds.), *The study of dyslexia (pp. 35-75).* New York: Plenum Publishers.

Beauvois, M. F., and Dérouesné, J. (1979). Phonological alexia: Three dissociations. *Journal of Neurology, Neurosurgery and Psychiatry, 42(12),* 1115–1124.

Berninger, V., and Graham, S. (1998). Language by hand: A synthesis of a decade of research in handwriting. *Handwriting Review, 12*, 11-25.

Berninger, V., Abbot, R., Rogan, L., Reed, E., Abbott, S., Brooks, A., Vaughan, K., and Graham, S. (1998). Teaching spelling to children with specific learning disabilities: The mind's ear and eye beat the computer or pencil. *Learning Disability Quarterly, 21(2),* 106-122.

Best, D. (1992). *The Rationality of Feeling*. London: Falmer.

Blachman, B. A. (2000). Phonological Awareness. In M.L. Kamil, P.B., Mosenthal, P.D., Pearson, and R. Barr (Eds.). *Handbook of Reading Research, (Vol. 3, pp.483–502).* New Jersey: Lawrence Erlbaum Associates.

Booth, J.N., and Boyle, J.M.E. (submitted). The Role of Inhibitory Functioning in Children's Reading Skills: Implications for Practice. *Educational Psychology in Practice.*

Bosman, A.M.T. and Van Orden, G.C.V. (1997). Why spelling is more difficult than reading. In C.A. Perfetti, L. Rieben and M. Fayol (Eds.), *Learning to spell: Research, theory and practice across languages (pp. 173-194).* Hillsdale New Jersey: Lawrence Erlbaum Associates.

Bower, G.H. (1998). An associative theory of memory. In M.A. Conway, S.E. Gathercole and C. Cornoldi (Eds.), *Theories of memory (Vol. II, pp. 25-60).* Hove, UK: Psychology Press.

Bowers, P.G., and Wolf, M. (1993). Theoretical links among naming speed, precise timing mechanisms and orthographic skill in dyslexia. *Reading and Writing: An Interdisciplinary Journal, 5(1),* 69–85.

Bradley, L. (1981). The organisation of motor patterns for spelling: An effective remedial strategy for backward readers. *Developmental Medicine and Child Neurology, 23(1),* 83-91.

Bradley, L., and Bryant, P.E. (1983). Categorizing sounds and learning to read: A causal connection. *Nature, 301 (3 Feb),* 419–421.

Bradley, L., and Bryant, P. E. (1985). *Rhyme and reason in reading and spelling (International Academy for Research in Learning Disabilities monograph series: No. 1).* Ann Arbor: University of Michigan Press.

Brady, S.A. (1997). Ability to encode phonological representations: An underlying difficulty in poor readers. In E. Blachman, (Ed.), *Foundations of Reading Acquisition and Dyslexia, (pp. 21-47).* Mahwah, New Jersey: Lawrence Erlbaum Publishers.

Brady, S., and Shankweiler, D. (1991). *Phonological processes in literacy: A tribute to Isabelle Y. Liberman.* Hillsdale, NJ: Lawrence Erlbaum Associates, Inc.

Brooks, G. (2002). *What Works for Children With Literacy Difficulties? The effectiveness of intervention schemes.* London: DES.

Brooks, G., Flanagan, N., Henkhuzens, Z., and Hutchison, D. (1998). *What Works for Slow Readers? The Effectiveness of Early Intervention Schemes.* Slough: NFER.

Brooks, P.L. (1995). The effectiveness of various teaching strategies in teaching spelling to a student with severe learning difficulties. *Educational and Child Psychology, 12(1),* 80-88.

Brooks, P. L., and Weeks, S. A. (1998). A comparison the responses of dyslexic, slow learning and control children to different strategies for teaching spellings. *Dyslexia, 4(4),* 212-222.

Brown, A.S. (1990). A review of recent research on spelling. *Educational Psychology Review, 2(4),* 365-397.

Brown, G.D.A., and Loosemore, R.P.W. (1994). Computational approaches to normal and impaired spelling. In G.D.A. Brown and N.C. Ellis (Eds.), *Handbook of Spelling: Theory, Process and Intervention, (pp3 19-336).* Chichester, UK: John Wiley.

Bruck, M., Genesee, F., and Caravolas, M. (1997). A crosslinguistic study of early literacy acquisition. In B. Blachman (Ed.), *Foundations of reading acquisition and dyslexia: Implications for early intervention (pp. 145–162).* Mahwah, NJ: Erlbaum.

Bryant, N.D., Drabin, I.R., and Gettinger, M. (1981). Effects of varying unit size on spelling achievement in learning disabled children. *Journal of Learning Disabilities, 14(4),* 200-203.

Bryant, P., and Bradley, L. (1980). Why children sometimes write words which they do not read. In U. Frith (Ed.), *Cognitive Processes in Spelling (pp. 355-370).* London: Academic Press.

Bryant, P., Nunes, T., and Bindman, M. (1997). Awareness of language in children who have reading difficulties: Historical comparisons in a longitudinal study. *Journal of Child Psychology and Psychiatry, 39(4),* 501-510.

Bryant, P., MacLean, M., Bradley, L., and Crossland, J. (1990). Rhyme and alliteration, phoneme detection and learning to read. Developmental Psychology, 26(3), 429-438.

Bull, R., and Scerif, G. (2001). Executive functioning as a predictor of children's mathematics ability: Inhibition, shifting and working memory. Developmental Neuropsychology, 19(3), 273–293.

Bullinaria, J.A. (1994). Connectionist Modelling of Spelling. *Proceedings of the 16th Annual Conference of the Cognitive Science Society, pp. 78-83.* Available at: http://www.cs.bham.ac.uk/~jxb/PUBS/CMS.pdf

Burns, J. M., and Richgels, D. J. (1989). An investigation of task requirements associated with the invented spellings of 4-year-olds with above average intelligence. *Journal of Reading Behavior, 21(1),* 1–14

Buschke, H. (1973). Selective reminding for analysis of memory and learning. *Journal of Verbal Learning and Verbal Behavior,12(5),*543-550.

Byrne, B., and Fielding-Barnsley, R. (1989). Phonemic awareness and letter knowledge in the child's acquisition of the alphabetic principle. *Journal of Educational Psychology, 81(3),* 313-321.

Cain, K., Oakhill, J., and Bryant, P. (2004). Children's reading comprehension ability: Concurrent prediction by working memory, verbal ability, and component skills. *Journal of Educational Psychology, 96(1),* 31–42.

Campbell, R. (1983). Writing nonwords to dictation. *Brain and Language, 19(1),* 153-178.

Cantor, J., and Engle, R.W. (1993). Working memory capacity as long-term memory activation: An individual-differences approach. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 19(5),* 1101–1114.

Caramazza, A., Miceli, G., Villa, G., and Romani, C. (1987). The role of the graphemic buffer in spelling: Evidence from a case of acquired dysgraphia. *Cognition, 26(1),* 59–85.

Caravolas, M., Hulme, C., and Snowling, M. (2001). The foundations of spelling ability: Evidence from a 3-year longitudinal study. *Journal of Memory and Language, 45(4),* 751-774.

Carrier, M. and Pashler, H. (1992). The influence of retrieval on retention. *Memory and Cognition, 20(6),* 633-642.

Case, R., Kurland, M. D., and Goldberg, J. (1982). Operational efficiency and the growth of short-term memory span. *Journal of Experimental Child Psychology, 33(3),* 386–404.

Cassar, M., and Treiman, R., (2004). Developmental Variations in Spelling. In C.A. Stone, E.R. Silliman, B.J. Ehren and K. Apel (Eds.), *Handbook of Language and Literacy (pp. 627-643).* London: The Guilford Press.

Castiglioni-Spalten, M. L., and Ehri, L. C. (2003). Phonemic Awareness Instruction: Contribution of Articulatory Segmentation to Novice Beginners' Reading and Spelling. *Scientific Studies of Reading, 7(1),* 25-52.

Cataldo, S., and Ellis, N.C. (1988). Interactions in the development of spelling, reading and phonological skills. *Journal of Research in Reading, 11(2),* 86-109.

Chase, C. (1986). Essay test scoring: Interaction of relevant variables. *Journal of Educational Measurement, 23(1),* 33-41

Chliounaki, K., and Bryant, P. (2007). How children learn about morphological spelling rules. *Child Development, 78(4),* 1360-1373.

Chomsky, C. (1979). Approaching reading through invented spelling. In L. B. Resnick, and P. A. Weaver (Eds.), *Theory and practice of early reading (Vol. 2, pp. 43-65).* Hillsdale, NJ: Lawrence Erlbaum Associates.

Chomsky, N., and Halle, M. (1968). *The sound pattern of English.* New York: Harper and Row.

Christiansen, M.H., and Chater, N. (2001). Connectionist psycholinguistics: capturing the empirical data. *Trends in Cognitive Sciences, 5(2),* 82-88.

Clarke, P., Hulme, C., and Snowling, M. (2005). Individual differences in RAN and reading: A response timing analysis. *Journal of Research in Reading, 28(2),* 73-86.

Cohen, J. (1988). *Statistical power analysis for the behavioral sciences (2nd ed.).* New York: Academic Press.

Colle, H.A., and Welsh, A. (1976). Acoustic masking in primary memory. *Journal of Verbal Learning and Verbal Behavior, 15(1),* 17-32.

Collette, F., and Van der Linden, M. (2002). Brain imaging of the central executive component of working memory. *Neuroscience and Biobehavioral Reviews, 26(2),* 105–125.

Coltheart, M., Curtis, B., Atkins, P., and Haller, M. (1993). Models of reading aloud: Dual-route and parallel-distributed-processing approaches. *Psychological Review, 100(4),* 589-608.

Compton, D. L., DeFries, J. C., and Olson, R. K. (2001). Are RAN and phonological awareness deficits additive in children with reading disabilities? *Dyslexia, 7(3),* 125–149.

Conlin, J.A., Gathercole, S.E., and Adams, J.W. (2005). Children's working memory: Investigating performance limitations in complex span tasks. *Journal of Experimental Child Psychology, 90(4),* 303–317.

Conrad, N.J. (2009). From reading to spelling and spelling to reading: Transfer goes both ways. *Journal of Educational Psychology, 100(4),* 869-878.

Conrad, R., and Hull, A.J. (1964). Information, acoustic confusion and memory span. *The British Journal of Psychology, 55(Nov),* 429-32.

Conway, A.R.A., Cowan, N., Bunting, M.F., Therriault, D.J., and Minkoff, S.R.B. (2002). A latent variable analysis of working memory capacity short-term memory capacity, processing speed, and general fluid intelligence. *Intelligence, 30(2),* 163-183.

Cormier, P., and Dea, S. (1997). Distinctive patterns of relationship of phonological awareness and working memory with reading development. *Reading and Writing, 9(3),* 193–206.

Cornwall, A. (1992). The relationship of phonological awareness, rapid naming, and verbal memory to severe reading and spelling disability. *Journal of Learning Disabilities, 25(8),* 532–538.

Cowan, N. (1995). *Attention and memory: An integrated framework.* New York: Oxford University Press.

Cowan, N. (1997). The development of working memory. In N. Cowan (Ed.), *The development of memory in childhood (pp.163–199).* Hove, UK: Psychology Press.

Cowan, N. (1999). An embedded-processes model of working memory. In A. Miyake and P. Shah (Eds.), *Models of working memory: Mechanisms of active maintenance and executive control (pp.62-101.)* Cambridge, UK: Cambridge University Press.

Cowan, N. (2001). The magical number 4 in short-term memory: A reconsideration of mental storage capacity. *Behavioral and Brain Sciences, 24(1),* 87-185.

Cowan, N. (2005). *Working memory capacity.* New York: Taylor and Francis.

Cowan, N., and Chen, Z. (2009). How chunks form in long-term memory and affect short-term memory limits. In A. Thorn and M Page (Eds.), *Interactions between short-term and long-term memory in the verbal domain (pp. 88-101).* Hove, East Sussex, UK: Psychology Press.

Cowan, N., Saults, J.S., and Morey, C.C. (2006). Development of working memory for verbal–spatial associations. *Journal of Memory and Language, 55(2),* 274–289.

Cowan, N., Day, L., Saults, J.S., Keller, T.A., Johnson, T., and Flores, L. (1992). The role of verbal output time in the effects of word length on immediate memory. *Journal of Memory and Language, 31(1),* 1-17.

Cowan, N., Wood, N.L., Wood, P.K., Keller, T.A., Nugent, L D., and Keller, C.V. (1998). Two separate verbal processing speeds contributing to verbal short-term memory span. *Journal of Experimental Psychology: General, 127(2),* 141–160.

Crowder, R. G. (1976). *Principles of learning and memory.* Hillsdale New Jersey: Lawrence Erlbaum Associates.

Cunningham, A., and Stanovitch, K. E. (1990). Early Spelling Acquisition: Writing Beats the Computer. *Journal of Educational Psychology, 82(1),* 159-62.

Daneman, M., and Carpenter, P.A. (1980). Individual differences in working memory and reading. *Journal of Verbal Learning and Verbal behaviour, 19(4),* 450-466.

Darch, C., Kim, S., Johnson, S., and James. H. (2000). The strategic spelling skills of students with leaning disabilities: The results of two studies. *Journal of Instructional Psychology, 27(1),* 15-26.

Dehn, M. J. (2008). *Working memory and academic learning.* New Jersey: John Wiley and Sons.

De Jong, P. (1998). Working memory deficits of reading disabled children. *Journal of Experimental Child Psychology, 70(2),* 75–95.

Della Sala, S., Gray, C., Baddeley, A. D., and Wilson, L. (1997). *Visual Patterns Test.* London: Thames Valley Test Publishing.

Della Sala, S., Gray, C., Baddeley, A.D, Allamano, N., Wilson, L. (1999) Pattern span: a tool for unwelding visuo-spatial memory. *Neuropsychologia, 37(10),* 1189–1199.

Dempster, F. N. (1996). Distributing and managing the conditions of encoding and practice. In E. L. Bjork and R. A. Bjork (Eds.), *Memory: Handbook of perception and cognition.* San Diego, CA.: Academic Press.

Denckla, M. B., and Rudel, R. (1976). Rapid automatized naming (RAN): Dyslexia differentiated from other learning disabilities. *Neuropsychologia,* 14(4), 471–479.

Department for Children, Schools and Families (DCSF). (2009). *National Curriculum Assessments at Key Stage 2 in England, 2008 (REVISED).* Available at: http://www.dcsf.gov.uk/rsgateway/DB/SFR/s000836/SFR06_2009_Final_Revised.pdf

Department for Education and Skills ,(DfES), (2005). *Higher Standards, Better Schools for All - More Choice for Parents and Pupils.* Available at: http://www.dfes.gov.uk/publications/schoolswhitepaper

Department for Education and Skills, (DfES). (2007). *Letters and Sounds: Principles and Practice of High Quality Phonics. Notes of Guidance for Practitioners and Teachers.* Available at: http://www.standards.dfes.gov.uk/local/clld/resources/letters_and_sounds/00282_2007BKT_EN.pdf

Department of Education for Northern Ireland (DENI). (1998). *The Code of Practice on the Identification and Assessment of Special Educational Needs.* Available at: http://www.deni.gov.uk/the_code_of_practice.pdf

DeStefano, D., and LeFevre, J. A. (2004). The role of working memory in mental arithmetic. *European Journal of Cognitive Psychology, 16(34),* 353–386.

D'Esposito, M., Detre, J. A., Alsop, D. C., Shin, R. K., Atlas, S., and Grossman, M. (1995). The neural basis of the central executive system of working memory. *Nature, 378(6554),* 279–281.

Dyslexia Scotland, (2005). *A Guide for Teachers.* Available at: http://www.dyslexiascotland.org.uk/documents/Guide%20for%20Teachers%20A4.pdf

Edelsky, C., Altwerger, B., and Fiores, B. (1991). *Whole language: What's the difference?* Portsmouth, NH: Heinemann.

Ehri, L. C. (1980). The development of orthographic images. In U. Frith (Ed.), *Cognitive Processes in Spelling (pp. 311-338).* London: Academic Press.

Ehri, L. C. (1987). Learning to read and spell words. *Journal of Reading Behavior, 19(1),* 5-31.

Ehri, L.C. (1997). Learning to read and learning to spell are one and the same, almost. In C.A. Perfetti, L. Rieben and M. Fayol (Eds.), *Learning to spell: Research,* *theory and practice across languages (pp. 237-269).* Hillsdale New Jersey: Lawrence Erlbaum Associates.

Ehri, L. C. (2005). Learning to Read Words: Theory, Findings, and Issues. *Scientific Studies of Reading, 9(2)*, 167–188.

Ehri, L. C., and Wilce, L. S. (1987). Does learning to spell help beginning readers learn to read words? *Reading Research Quarterly, 22(1)*, 47–65.

Elbro, C. (1996). Early linguistic abilities and reading development: A review and a hypothesis. *Reading and Writing: An Interdisciplinary Journal, 8(6)*, 453-485.

Ellis, A.W. (1982). Spelling and writing (and reading and speaking). In A.W. Ellis (Ed.), *Normality and Pathology in Cognitive Functions (pp. 113-143).* New York: Academic Press.

Ellis, A.W., and Young, A.W. (1988). *Human cognitive neuropsychology.* London: Lawrence Erlbaum Associates.

Ellis, N. (1997). Interactions in the development of reading and spelling: Stages, strategies, and exchange of knowledge. In C.A. Perfetti, L. Rieben and M. Fayol (Eds.), *Learning to spell: Research, theory and practice across languages (pp. 271-294).* Hillsdale New Jersey: Lawrence Erlbaum Associates.

Engle, R.W. (2002). Working Memory Capacity as Executive Attention. *Current Directions in Psychological Science, 11(1)*, 19-23.

Engle, R.W., Cantor, J., and Carullo, J.J. (1992). Individual differences in working memory for comprehension: A test of four hypotheses. *Journal of Experimental Psychology: Learning Memory and Cognition, 18(5)*, 972- 992.

Engle, R. W., Kane, M. J., and Tuholski, S. (1999a). Individual differences in working memory capacity and what they tell us about controlled attention, general fluid intelligence, and functions of the prefrontal cortex. In A. Miyake and P. Shah (Eds.) *Models of working memory: Mechanisms of active maintenance and executive control (pp. 102–134).* Cambridge, England: Cambridge University Press.

Engle, R. W., Tuholski, S. W., Laughlin, J. E., and Conway, A. R. (1999b). Working memory, short-term memory, and general fluid intelligence: A latent-variable approach. *Journal of Experimental Psychology: General 128(3),* 309–331.

Englert, C.S., Hiebert, E.H., and Stewart, S.R. (1985). Spelling unfamiliar words by an analogy strategy. *The Journal of Special Education, 19(3),* 291-306.

Ericsson, K. A., and Chase, W.G. (1982). Exceptional Memory. *American Scientist, 70(6),* 607-615.

Ericsson, K. A., and Delaney, P. F. (1999). Long-term working memory as an alternative to capacity models of working memory in everyday skilled performance. In A. Miyake, and P. Shah (Eds.), *Models of working memory: mechanisms of active maintenance and executive control (pp. 257–297).* New York: Cambridge University Press.

Ericsson, K.A., and Kintsch, W. (1995). Long-term working memory. *Psychological Review, 102(2),* 211-245.

Ericsson, K.A., Patel, V.L., and Kintsch, W. (2000). How experts' adaptations to representative task demands account for the expertise effect in memory recall: Comment on Vicente and Wang (1998). *Psychological Review, 107(3),* 578-592.

Estyn (Her Majesty's Inspectorate for Education and Training in Wales). (2001). *Raising Standards of Spelling in English Primary Schools.* Available at: http://www.estyn.gov.uk/publications/GoodStdSpell_prim.pdf

Farmer, E.W., Berman, J.V.F., and Fletcher , Y.l. (1986). Evidence for a visuo-spatial scratch-pad in working memory. *The Quarterly Journal of Experimental Psychology: A*, 38(4), 675-688.

Field, A. (2005). *Discovering statistics using SPSS (2nd edition)*. London: Sage Publications.

Folk, J. R. and Rapp, B. (2004). Interaction of lexical and sublexical information in spelling: Evidence from nonword priming. *Applied Psycholinguistics, 25(4),* 565-586.

Foorman, B. R., Francis, D. J., Novy, D. M., and Liberman, D. (1991). How letter-sound instruction mediates progress in first-grade reading and spelling. *Journal of Educational Psychology, 83(4),* 456–469.

Frederickson, N., and Wilson, J. Phonological awareness training: A new approach to phonics teaching. *Dyslexia, 2(2),* 101-120.

Fresch, M. J. (2007). Teachers' concerns about spelling instruction: A national survey. *Reading Psychology, 28(4),* 301-330.

Friedman, N. P., and Miyake, A. (2000). The Reading Span Test and Its Predictive Power for Reading Comprehension Ability. *Journal of Memory and Language, 51(1),* 136-158.

Friedman, N. P., and Miyake, A. (2005). Comparison of Four Scoring Methods for the Reading Span Test. Behavior Research Methods, 37(4), 581-590.

Frith, U. (1980). Unexpected spelling problems. In U. Frith (Ed.), *Cognitive Processes in Spelling (pp. 495-515).* London: Academic Press.

Frith, U. (1985). Beneath the surface of developmental dyslexia. In K. Patterson, J. Marshall, and M. Coltheart (Eds.), *Surface Dyslexia (pp. 301–330).* London: Lawrence Erlbaum Associates.

Frith, U. (2002). Resolving the paradoxes of dyslexia. In Reid, G. and Wearmouth, J. (Eds.) *Dyslexia and Literacy: Theory and Practice (pp. 45-68).* John Wiley and Sons.

Frost, R. (1998). Toward a strong phonological model of reading: True issues and false trails. *Psychological Bulletin, 123(1),* 71-99.

Fry, A. F., and Hale, S. (1996). Processing speed, working memory, and fluid intelligence: Evidence for a developmental cascade. *Psychological Science, 7(4),* 237–241.

Fulk, B.M. (1996). The effects of combined strategy and attribution training on LD adolescents' spelling performance. *Exceptionality, 6(1),* 13-27.

Fulk, B.M., and Stormont-Spurgin, M. (1995). Spelling interventions for students with disabilities: A review. *Journal of Special Education, 28(4),* 488 -513.

Gathercole, S. E. (1998). The development of memory. *Journal of Child Psychology and Psychiatry, 39(1),* 3–27.

Gathercole, S. E. (1999). Cognitive approaches to the development of short-term memory. *Trends in Cognitive Science, 3(11),* 410–418.

Gathercole, S. E. (2006). Nonword repetition and word learning: The nature of the relationship. *Applied Psycholinguistics, 27(1),* 513-543.

Gathercole, S.E., and Alloway, T.P. (2006). Practitioner Review: Short-term and working memory impairments in neurodevelopmental disorders: diagnosis and remedial support. *Journal of Child Psychology and Psychiatry, 47(1),* 4-15.

Gathercole, S. E., and Baddeley, A. D. (1989). Evaluation of the role of phonological STM in the development of vocabulary in children: A longitudinal study. *Journal of Memory and Language, 28(2),* 200–213.

Gathercole, S. E., and Baddeley, A. D. (1993). *Working Memory and Language.* Hillsdale, New Jersey: Erlbaum.

Gathercole, S. E., and Hitch, G. J. (1993). Developmental changes in short-term memory: A revised working memory perspective. In A. Collins, S. E. Gathercole, M. A. Conway, and P. E. Morris (Eds.), *Theories of memory (pp. 189–210).* Hove, England: Erlbaum.

Gathercole, S.E., and Pickering, S.J. (2000a). Working memory deficits in children with low achievements in the national curriculum at seven years of age. *British Journal of Educational Psychology,* 70(2), 177-194.

Gathercole, S. E., and Pickering, S. J. (2000b). Assessment of working memory in six- and seven-year-old children. *Journal of Educational Psychology, 92(2),* 377-390.

Gathercole, S. E. and Pickering, S. J. (2001). Working memory deficits in children with special educational needs. *British Journal of Special Education, 28(2),* 89-97.

Gathercole, S. E., Alloway, T.P., Willis, C., and Adams, A.-M. (2006). Working memory in children with reading disabilities. *Journal of Experimental Child Psychology, 93(3),* 265-281.

Gathercole, S. E., Pickering, S. J., Ambridge, B., and Wearing, H. (2004a). The structure of working memory from 4 to 15 years of age. *Developmental Psychology, 40(2),* 177–190.

Gathercole, S.E., Pickering, S.J., Knight, C., and Stegmann, Z. (2004b). Working memory skills and educational attainment: Evidence from National Curriculum assessments at age 7 and 14 years. *Applied Cognitive Psychology, 18(1),* 1-16.

Gathercole, S. E., Willis, C. S., Baddeley, A. D. and Emslie, H. (1994). The Children's Test of Nonword Repetition: A test of phonological working memory. *Memory, 2(2),* 103-127.

Gathercole, S.E., Willis, C.S., Emslie, H., and Baddeley, A.D. (1992). Phonological memory and vocabulary development during the early school years: A longitudinal study. *Developmental Psychology, 28(5),* 887-898.

Gentry, J. (1977). A study of the orthographic strategies of beginning readers. *Unpublished doctoral dissertation.* University of Virginia, Charlottesville.

Gentry, J.R. (1982). An analysis of developmental spelling in GYNS AT WRK. *Reading Teacher, 36(2),* 192-200.

Gentry, J.R. (2000). A retrospective on invented spelling and a look forward. *The Reading Teacher, 54(3),* 318-332.

Georgiou, G.K., Das, J.P., and Hayward, D.V. (2008). Comparing the contribution of two tests of working memory to reading in relation to phonological awareness and rapid naming speed. *Journal of Research in Reading, 31(3),* 302–318.

Gerber, M.M. (1986). Generalization of spelling strategies by LD students as a result of contingent imitation modelling and mastery criteria. *Journal of Learning Disabilities, 19(9),* 530-537.

Gerber, M.M., and Hall, R.J. (1987). Information processing approaches to studying spelling deficiencies. *Journal of Learning Disabilities, 20(1),* 34-42.

Gettinger, M. (1993). Effects of error correction on third graders' spelling. *Journal of Educational Research, 87(1),* 39-45.

Gettinger, M., Bryant, N.D., and Fayne, H.R. (1982). Designing spelling instruction for learning-disabled children: An emphasis on unit size, distributed practice, and training for transfer. *The Journal of Special Education, 16(4),* 439-448.

Gillingham, A., and Stillman, B. (1997). *The Gillingham manual: Remedial training for children with specific disability in reading, spelling and penmanship: 7th ed.* Cambridge, MA: Educators Publishing Service.

Glaser, R., and Chi, M. T. H. (1988). Overview. In M. T. H. Chi, R. Glaser, and M. J. Farr (Eds.), *The nature of expertise (pp. xv–xviii).* Hillsdale, NJ: Erlbaum.

Gobet, F., and Clarkson, G. (2005). Chunks in expert memory: evidence for the magical number four ... or is it two? *Memory, 12(6),* 732-747.

Gombert, J.E. (1992). *Metalinguistic development.* Hemel Hempstead, England: Harvester Wheatsheaf.

Goswami, U. (1988). Children's use of analogy in learning to spell. *British Journal of Developmental Psychology, 6(1),* 1-22.

Goswami, U. (2002). Phonology, Reading Development, and Dyslexia: A Cross-linguistic Perspective. *Annuals of Dyslexia, 52(1),* 139-163.

Goswami, U., and Bryant, P., (1990). *Phonological skills and learning to read.* Hove, UK: Lawrence Erlbaum Associates.

Graham, S. (1983). Effective spelling instruction. *The Elementary School Journal, 83(50),* 560-567.

Graham, S. (1999). Handwriting and spelling instruction for students with learning disabilities: A review. *Learning Disability Quarterly, 22(2),* 78-98.

Graham, S. (2000). Should the natural learning approach replace spelling instruction? *Journal of Educational Psychology, 92(2),* 235–247.

Graham, S., and Freeman, S. (1985). Strategy training and teacher- vs. student-controlled study conditions: Effects on LD students' spelling performance. *Learning Disability Quarterly, 8(4),* 267-274.

Griffith, P.L. (1991). Phonemic awareness helps first graders invent spellings and third graders remember correct spellings. *Journal of Reading Behavior, 23(2),* 215-233.

Grskovic. J.A., and Belfiore, P.J. (1996). Improving the spelling performance of students with disabilities. *Journal of Behavioral Education, 6(3),* 343-354.

Guérard, K., Tremblay, S., and Saint-Aubin, J. (2009). Similarity and binding in memory: Bound to be detrimental. *The Quarterly Journal of Experimental Psychology, 61(1),* 26-32.

Guza, D. S., and McLaughlin, T. F. (1987). A comparison of daily and weekly testing on student spelling performance. *Journal of Educational Research, 80(6),* 373-376.

Hambrick, D. Z., and Engle, R. W. (2002). Effects of Domain Knowledge, Working Memory Capacity, and Age on Cognitive Performance: An Investigation of the Knowledge-Is-Power Hypothesis. *Cognitive Psychology, 44(4),* 339–387.

Hanna, P. R., Hanna, J. S., Hodges, R. E., and Rudorf, H. (1966). *Phoneme-grapheme correspondences as cues to spelling improvement.* Washington, DC: U.S. Office of Education.

Hannay, H.J. and Levin, H.S. (1985). Selective reminding test: An examination of the equivalence of four forms. *Journal of Clinical and Experimental Neuropsychology, 7(3),* 251-263.

Hansen, J., and Bowey, J. A. (1994). Phonological analysis skills, verbal working memory, and reading ability in second-grade children. *Child Development, 65(3),* 938-950.

Hartley, A.A., Speer, N.K., Jonides, J, Reuter-Lorenz, P.A, and Smith, E. (2001). Is the dissociability of working memory systems for name identity, visual-object identity, and spatial location maintained in old age? *Neuropsychology, 15(1),* 3–17.

Harward, S.V., Allred, R.A., and Sudweeks, R.R. (1994). The effectiveness of four self-corrected spelling test methods. *Reading Psychology,15(4),* 245-271.

Hatcher, J. and Snowling, M.J. (2002). The Phonological Representations Hypothesis of Dyslexia: From Theory to Practice. In Reid, G. and Wearmouth, J. (Eds.) *Dyslexia and Literacy: Theory and Practice (pp. 69-83).* John Wiley and Sons.

Hebb, D.O. (1961). Distinctive features of learning in the higher animal. In J. E. Delafresnaye (Ed.), *Brain mechanisms and learning (pp. 37–46).* New York: Oxford University Press.

Hecker, R., and Mapperson, B. (1997). Dissociation of visual and spatial processing in working memory. *Neuropsychologia, 35(5),* 599–603.

Henderson, E. H. (1990). *Teaching spelling (2nd ed.).* Boston, MA: Houghton Mifflin.

Henson, R. (2001). Neural working memory. In J. Andrade (Ed.), *Working memory in perspective (pp. 151–173).* Hove, England: Psychology Press.

Henson, R., Burgess, N., and Frith, C. D. (2000). Recoding, storage, rehearsal and grouping in verbal short-term memory: An fMRI study. *Neuropsychologia, 38(4),* 426–440.

Her Majesty's Inspectorate of Education (HMIE), (2001). *Standards and Quality in Primary and Secondary Schools: 1998-2001.* Available at: http://www.hmie.gov.uk/documents/publication/sqpss.pdf

Her Majesty's Inspectorate of Education (HMIE), (2006). *Improving Scottish Education: A report by HMIE on inspection and review 2002-2005.* Available at: http://www.hmie.gov.uk/ise/hmieise.pdf

Hester, R., and Garavan, H. (2005). Working memory and executive function: The influence of content and load on the control of attention. Memory and Cognition, 33(2), 221-233.

Hillis, A. E., and Caramazza, A. (1991). Representation of grammatical categories in the brain. *Journal of Cognitive Neuroscience, 7(3),* 396-407.

Hitch, G.J., Towse, J.N., and Hutton, U. (2001). What limits children's working memory span? Theoretical accounts and applications for scholastic development. *Journal of Experimental Psychology, 130(2),* 184-198.

Hitch, G.J., Woodin, M.E., and Baker, S. (1989a). Visual and phonological components of working memory in children. *Memory and Cognition, 17(2),* 175-185.

Hitch, G.J., Halliday, M.S., Dodd, A., and Littler, J.E. (1989b). Development of rehearsal in short-term memory: Differences between pictorial and spoken stimuli. *British Journal of Developmental Psychology, 7(4),* 347–362.

Hitch, G. J., Halliday, M. S., Schaafstal, A. M., and Heffernan, T. M. (1991). Speech, "inner speech", and the development of short-term memory: Effects of picture labelling on recall. *Journal of Experimental Child Psychology, 51 (2),* 220-234.

Hitch, G.J., Halliday, S., Schaafstal, A.M., and Schraagen, J.M. (1988). Visual working memory in young children. *Memory and Cognition. 16(2),* 120-32.

Horn, E. (1919). Principles of methods in teaching spelling as derived from scientific investigation. In G. Whipple (Ed.), *Eighteenth Yearbook, National Society for the Study of Education.* Bloomington, Ind.: Public School Publishing.

Houghton, G., and Zorzi, M. (2003). Normal and impaired spelling in a dual-route architecture. *Cognitive Neuropsychology, 20(2),* 115-162.

Hulme, C, (1981). *Reading Retardation and Multi-Sensory Teaching.* London: Routledge and Kegan Paul.

Hulme, C. (1987). The effects of acoustic similarity on memory in children: A comparison between visual and auditory presentation. *Applied Cognitive Psychology, 1(1),* 45-51.

Hulme, C., and Bradley, L. (1984). An experiential study of multi-sensory teaching with normal and retarded readers. In R.N. Malatesha and H.A. Whitaker (Eds.), *Dyslexia: A Global Issue (pp. 431-443).* The Hague: NATO ASI Series, Martinus Nijhoff.

Hulme, C., and Snowling, M. (1992). Deficits in output phonology: An explanation of reading failure? *Cognitive Neuropsychology, 9(1),* 47-72.

Hulme, C., Snowling, M., Caravolas, M., and Carroll, J. (2005). Phonological Skills Are (Probably) One Cause of Success in Learning to Read: A Comment on Castles and Coltheart. *Scientific Studies of Reading, 9(4),* 351 – 365.

Hulme, C., Thomson, N., Muir, C., and Lawrence, A. (1984). Speech rate and the development of short-term memory span. *Journal of Experimental Child Psychology, 38(2),* 241–253.

Hulme, C., Roodenrys, S., Schweickert, R., Brown, G.D.A., Martin, S., and Stuart, G. (1997). Word-frequency effects on short-term memory tasks: Evidence for a redintegration process in immediate serial recall. *Journal of Experimental Psychology: Learning, Memory, and Cognition. 23(5),* 1217-1232.

Hurry, J., Bryant, P., Nunes, T., and Pretzlik, U. (2005) *Teachers' awareness of morphemes.* Available at: http://www.education.ox.ac.uk/uploaded/teachersawarenessofmorphemes2005_1.pdf

Institute of Education Sciences (2006). *What Works Clearinghouse Evidence Standards for Reviewing Studies.* Available at: http:www.whatworks.ed.gov/reviewprocess/study_standards_final.pdf

Isaacs, E. B., and Vargha-Khadem, F. (1989). Differential course of development of spatial and verbal memory span: A normative study. *British Journal of Developmental Psychology, 7(4),* 377–380.

Jacobs, J. (1887). Experiments on "prehension." *Mind, 12(45),* 75–79.

Jarrold, C., and Towse, J.N. (2006). Individual differences in working memory. *Neuroscience, 139(1),* 39-50.

Jarvis, H. L., and Gathercole, S. E. (2003). Verbal and non-verbal working memory and achievements on national curriculum tests at 11 and 14 years of age. *Educational and Child Psychology, 20(3),* 123-140.

Jefferies, E., Frankish, C., and Lambon Ralph, M. A. (2006). Lexical and semantic influences on item and order memory in immediate serial recognition: Evidence from a novel task. *Quarterly Journal of Experimental Psychology, 59(5),* 949–964.

Jefferies, E., Frankish, C., and Noble, K. (in press). Lexical coherence in short-term memory: Strategic reconstruction or "semantic glue"? The Quarterly Journal of Experimental Psychology:A.

Jefferies, E., Lambon Ralph, M.A., and Baddeley, A.D. (2004). Automatic and controlled processing in sentence recall: The role of long-term and working memory. *Journal of Memory and Language, 5(8),* 623–643.

Johnston, F. R. (2001). Exploring teachers' spelling practices and beliefs. *Reading research and Instruction, 40(2),* 143-156.

Jorm, A. F. (1983). Specific reading retardation and working memory: A review. *British Journal of Psychology, 74(3),* 311–342.

Juel, C., Griffith, P.L., and Gough, P.B. (1986). Acquisition of literacy: A longitudinal study of children in first and second grade. *Journal of Educational psychology, 78(4),* 243-255.

Just, M. A., and Carpenter, P. A. (1992). A capacity theory of comprehension: Individual differences in working memory. *Psychological Review, 99(1),* 122–149.

Kane, M.J., Bleckley, M.K., Conway, A.R.A., and Engle, R.W. (2001). A controlled –attention view of working memory capacity. *Journal of Experimental Psychology, 130(2),* 169-183.

Kane, M. J. and Engle, R. W. (2003). Working-memory capacity and the control of attention: The contributions of goal neglect, response competition, and task set to stroop interference. *Journal of Experimental Psychology General, 132(1),* 47-70.

Kauffman, J.M., Hallahan, D.P., Haas, K., Brame, T., and Boren, R. (1978). Imitating children's' errors to improve their spelling performance. *Journal of Learning Disabilities, 11(4),* 33-38.

Kearney, C. A., and Drabman, R.S. (1993). The write-Say method for improving spelling accuracy in children with learning disabilities. *Journal of Learning Disabilities, 26(1),* 52-56.

Kessler, B., and Treiman, R. (2003). Is English spelling chaotic? Misconceptions concerning its irregularity. *Reading Psychology, 24(3and4),* 267-289.

Klauer, K.C., and Zhao, Z .(2004). Double dissociations in visual and spatial short-term memory. *Journal of Experimental Psychology: General, 133(3),* 355–381.

Kreiner, D.S. (1992). Reaction time measures of spelling: testing a two-strategy model of skilled spelling. *Journal of Experimental Psychology: Learning, Memory and Cognition. 18(4),* 765-776.

Kreiner, D.S., and Gough, P.B. (1990). Two ideas about spelling: rules and word-specific memory. *Journal of Memory and Language, 29(1),* 103-118.

Kreiner, D.S., Schnakenberg, S. D., Green, A. G., Costello, M. J., and McClin, A. F. (2002). Effects of spelling errors on the perception of writers. *Journal of General Psychology, 129(1),* 5–18.

Kyllonen, P.C., and Christal, R.E. (1990). Reasoning ability is (little more than) working-memory capacity?! *Intelligence, 33(4),* 1–64.

Lamb, B.C. (1992a). *A National Survey of UK Undergraduates' Standards of English.* London: Queen's English Society.

Lamb, B.C. (1992b). The Spelling Standards of Undergraduates, 1997-98. *Journal of the Simplified Spelling Society, 24,* 11-17. Available at: http://www.spellingsociety.org/journals/j24/under.php.

Law, D. J., Morrin, K. A., and Pellegrino, J. W. (1995). Training effects and working memory contributions to skill acquisition in a complex coordination task. *Learning and Individual Differences, 7(3),*207-234.

Learndirect, (2007). *Poor basic skills are costing firms.* Available at: http://64.233.183.104/search?q=cache:u5zUWfu32uMJ:www.tvu.ac.uk/employers/m arch.pdf+learndirect+surveyandhl=enandct=clnkandcd=6andgl=ukandclient=firefox-a

Leather, C.V., and Henry, L.A. (1994). Working memory span and phonological awareness tasks as predictors of early reading ability. *Journal of Experimental and Child Psychology, 58(1),* 88-111.

Lennox, C., and Siegel, L. S. (1996). The development of phonological rules and visual strategies in average and poor spellers. *Journal of Experimental Child Psychology, 62(1),* 60–83.

Lennox, C., and Siegel, L. S. (1998). Phonological and orthographic processes in good and poor spellers. In C. Hulme and R. Malatesha Joshi (Eds.), *Reading and spelling development and disorders (pp. 395-404).* London: Lawrence Erlbaum Associates.

Liberman, I.Y., Mann, V.A., Shankweiler, D. and Werfelmen, M. (1982). Children's memory for recurring linguistic and nonlinguistic material in relation to reading ability. *Cortex, 18(3),* 367-376.

Logie, R.H. (1986). Visuo-spatial processing in working memory. *The Quarterly Journal of Experimental Psychology: A, 38(2),* 229-247.

Logie, R.H. (1995). *Visuo-spatial working memory.* Hove, UK: Lawrence Erlbaum Associates Ltd.

Logie, R.H., and Pearson, D.G. (1997). The inner ear and the inner scribe of visuo-spatial working memory: Evidence from developmental fractionation. *European Journal of Cognitive Psychology, 9(3),* 241–257.

Logie, R.H., Cocchini, G., Della Sala, S., and Baddeley, A.D. (2004). Is there a specific capacity for dual-task coordination? Evidence from Alzheimer's disease. *Neuropsychology, 18(3),* 504-515.

Logie, R.H., Della Sala, S. Wynn, V., and Baddeley, A.D. (2000). Visual similarity effects in immediate verbal serial recall. *The Quarterly Journal of Experimental Psychology:A, 53 (3),* 626-646.

Luck, S.J., and Vogel, E.K. (1997). The capacity of visual working memory for features and conjunctions. *Nature, 390(6657),* 279–281.

Lundberg, I., Frost, J., and Petersen, O.P. (1988). Effects of an extensive program for stimulating phonological awareness in preschool children. Reading research Quarterly, 23(3), 261-284.

MacArthur, C. A., Graham, S., Haynes, J. B., and DeLaPaz, S. (1996). Spell checkers and students with learning disabilities: Performance comparisons and impact on spelling. *Journal of Special Education, 30(1),* 35-57.

Margolin, D. I. (1994). The neuropsychology of writing and spelling: Semantic, phonological, motor, and perceptual processes. *Quarterly Journal of Experimental Psychology A, 36(3),* 459-489.

Marshall, J., and Powers, J. (1969). Writing neatness, composition errors, and essay grades. *Journal of Educational Measurement, 6(2),* 97-101.

McBride-Chang, C., and Manis, F. R. (1996). Structural invariance in the associations of naming speed, phonological awareness, and verbal reasoning in good and poor readers: A test of the double deficit hypothesis. *Reading and Writing, 8(4),* 323–339.

McCallum, R.S., Bell, S.M., Wood, M.S., Below, J.L., Choate, S.M., and McCane, S.J. (2006). What Is the Role of Working Memory in Reading Relative to the Big Three Processing Variables (Orthography, Phonology, and Rapid Naming)? *Journal of Psychoeducational Assessment, 24(3),* 243-259.

McGuffin, M.E., Martz, S.A., and Heron, T.E. (1997). The effects of self-correction versus traditional spelling on the spelling performance and maintenance of third grade students. *Journal of Behavioral Education, 7(4),* 463-476.

McGuigan, F.J. (1978). *Experimental psychology: a methodological approach (3rd edition).* Englewood Cliffs, N.J.: Prentice Hall.

McLeod, J., and Greenough, P. (1980). The importance of sequencing as an aspect of short-term memory in good and poor spellers. *Journal of Learning Disabilities, 13(5),* 255-281.

McNaughton, D., Hughes, C.A., and Clark, K. (1994). Spelling Instruction for Students with Learning Disabilities: Implications for Research and Practice. *Learning Disability Quarterly, 17(3),* 169-185.

McNeish, J., Heron, T.E., and Okyere, B. (1992). Effects of self-correction on the spelling performance of junior high students with learning disabilities. *Journal of Behavioral Education, 2(1),* 17-27.

Meyer, M.S., Wood, F.B., Hart, L.A., and Felton, R.H. (1998). Selective predictive value of rapid automatized naming in poor readers. *Journal of Learning Disabilities, 31(2),* 106–117.

Miceli, G., and Capasso, R. (2006). Spelling and dysgraphia. *Cognitive Neuropsychology, 23(1),* 110-134.

Miller, G.A. (1956). The magical number seven, plus or minus two: Some limits on our capacity for processing information. *Psychological Review, 63,* 81-97.

Milner, B. (1971). Interhemispheric differences in the localisation of psychological processes in man. *British Medical Bulletin, 27(3),* 272-277.

Miyake, A., Friedman, N. P., Emerson, M.J., Witzki, A.H., Howerter, A. and Wager, T.D. (2000). The unity and diversity of executive functions and their contributions to complex "frontal lobe" tasks: A latent variable analysis. *Cognitive Psychology, 41(1),* 49–100.

Miyake, A., Friedman, N.P., Rettinger, J.A., Shah, P., and Hegarty, P. (2001). How are visuospatial working memory, executive functioning, and spatial abilities related? A latent-variable analysis. *Journal of Experimental Psychology: General, 130(4),* 621–640.

Miyake, A., and Shah, P. (Eds.). (1999). *Models of working memory: Mechanisms of active maintenance and executive control.* New York: Cambridge University Press.

Moats, L.C. (1995). *Spelling: Development, Disabilities, and Instruction.* Baltimore, Md.: York Press Incorporated.

Moats, L.C. (2007). Can you teach an older student to spell? In L. Denti and G.R. Guerin (Eds.), *Effective Practice for Adolescents with Reading and Literacy Challenges (pp.65-81).* Oxton, UK: Routledge.

Moats, L.C. and Farrell, M.L. (2005). Multisensory structured language education. In J. R. Birsh (Ed.), *Multisensory teaching of basic language skills (2nd edition).* London: Brookes.

Mohr, H.M., and Linden, D.E.J. (2005). Separation of the systems for color and spatial manipulation in working memory revealed by a dual-task procedure. *Journal of Cognitive Neuroscience, 17(2),* 355-66.

Montgomery, D.J., Karlan, G.R., and Coutinho, M. (2001). The effectiveness of word processor spell checker programs to produce target words for misspellings generated by students with learning disabilities. *Journal of Special Education technology, 16(2),* 27-41.

Monsell, S., and Driver, J. (Eds.). (2000). *Control of cognitive processes: Attention and performance XVIII.* Cambridge, MA: MIT Press.

Morris, D., Nelson, L., and Perney, J. (1986). Exploring the concept of "spelling instructional level" through the analysis of error-hypes. *The Elementary School Journal, 87(2),* 180-200.

Morris, D., Blanton, L., Blanton, W.E., Nowacek, J., and Perney, J. (1995). Teaching low achieving spellers at their 'instructional level'. *Elementary School Journal, 96(2),* 163-177.

Morrison, S. R., and Siegel, L. S. (1991). Learning disabilities: A critical review of definitional and assessment issues. In J.E. Obrzut and G.W. Hynd (Eds.), *Neurological foundations of learning disabilities (pp. 79-97).* San Diego, CA: Academic Press.

Morton, J. (1980). The logogen model and orthographic structure. In U. Frith (Ed.), *Cognitive Processes in Spelling (pp. 117-133).* London: Academic Press.

Morton, W.L., Heward, W.L., and Alber, S.R. (1998). When to self-correct?: A comparison of two procedures on spelling performance. *Journal of Behavioral Education, 8(3),* 321-335.

Murphy, J.F., Hern, C.L., Williams, R.L., and McLaughlin, T.F. (1990). The effects of the copy, cover, compare approach in increasing spelling accuracy with learning disabled students. *Contemporary Educational Psychology, 15(4),* 378-386.

Murre, J.M.J., Wolters, G., and Raffone, A. (2006). Binding in working memory and long-term memory: towards an integrated model. In H.D. Zimmer, A. Mecklinger and U. Lindenberger (Eds.), *Handbook of binding and memory: perspectives from cognitive neuroscience (pp221-250).* Oxford, UK: Oxford University Press.

Muter, V. (2004). Phonological skills, learning to read, and dyslexia. In M. Turner and J. Rack, (Eds.), *The Study of Dyslexia (pp. 92-129).* New York: Plenum Publishers.

Muter, V., and Snowling, M. (1998). Concurrent and Longitudinal Predictors of Reading: The Role of Metalinguistic and Short-Term Memory Skills. *Reading Research Quarterly, 33(3),* 320-337.

Muter, V., Hulme, C., Snowling, M., and Taylor, S. (1998). Segmentation, not rhyming, predicts early progress in learning to read. *Journal of Experimental Child Psychology, 71(1),* 3-27.

Nairne, J. S. (1990). A feature model of immediate memory. *Memory and Cognition, 18(3),* 251–269.

Nation, K., and Hulme, C. (1998). The role of analogy in early spelling development. In C. Hulme and R. M. Joshi (Eds.), *Reading and spelling development and disorders (pp. 433–445).* Mahwah, NJ: Lawrence Erlbaum Associates.

Neath, I. (2000). Modelling the effects of irrelevant speech on memory. *Psychonomic Bulletin and Review, 7(3),* 403-423.

Neath, I., and Surprenant, A.M. (2005). Mechanisms of memory. In K. Lamberts and R. L. Goldstone (Eds.), *Handbook of cognition (pp. 221-238).* London: Sage. Available at: http://memory.psych.mun.ca/pubs/reprints/Neath%20and%20Surprenant%20(2005).pdf

Nelson, C. A. (1995). The ontogeny of human memory: A cognitive neuroscience perspective. *Developmental Psychology, 31(5),* 723–738.

Nelson, C. A. (2000). Neural plasticity and human development: The role of early experience in sculpting memory systems. Developmental Science, 3(2),115–136.

Nies, K.A., and Belfiore, P.J. (2006). Enhancing spelling performance in students with learning disabilities. *Journal of Behavioral Education, 15(3)*, 163-170.

Norman, D., and Shallice, T. (1980). *Attention to action: willed and automatic control of behaviour (CHIP Report 99).* San Diego, CA: University of California San Diego. Available at: http://books.google.com/books?hl=enandlr=andid=-KhAi3miVDkCandoi=fndandpg=PA376anddq=Attention+to+action++normanandots=OSbHVpzIM5andsig=7F4CXoMEmwubljXqSryIaT1kG3U

Norton, E. S., Kovelman, I., and Petitto, L. (2007). Are There Separate Neural Systems for Spelling? New Insights into the Role of Rules and Memory in Spelling from Functional Magnetic Resonance Imaging. *Mind, Brain and Education, 1(1)*, 48-59.

Nulman, J.A.H., and Gerber, M.M. (1984). Improving spelling performance by imitating a child's errors. *Journal of Learning Disabilities, 17(6)*, 328-333.

Nunes, T., and Bryant, P. (2009). *Children's reading and spelling.* Chichester, West Sussex, U.K.: Malden, MA: Wiley-Blackwell.

Nunes, T., Bryant, P., and Bindman, M. (1997). Morphological spelling strategies: Developmental stages and processes. *Developmental Psychology, 33(4)*, 637-649.

Nunes, T., Bryant, P., and Bindman, M. (2006). The effects of learning to spell on children's awareness of morphology. *Reading and Writing: An Interdisciplinary Journal, 19(7)*, 767-787.

Nunes, T., Bryant, P., and Olsson, J. M. (2003). Learning morphological and phonological spelling rules: An intervention study. *Scientific Studies in Reading, 7(3)*, 289-307.

Oakhill, J., and Kyle, F. (2000). The Relation between Phonological Awareness and Working Memory. *Journal of Experimental Child Psychology, 75(2)*, 152-164.

Oberauer, K. (2002). Access to information in working memory: Exploring the focus of attention. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 28(3)*, 411–421.

Oberauer, K., Süß, H-M., Wilhelm, O., and Wittmann, W.W. (2003). The multiple faces of working memory: Storage, processing, supervision, and coordination. *Intelligence, 31(2),* 167–193.

Office for Standards in Education (Ofsted). (2004). *Standards and Quality.* Available at: http://www.archive2.official documents.co.uk/document/deps/ofsted/170/ofsted_annual_rep_20jan04.pdf

Olsen, A., and Caramazza, A. (1994). Representation and Connectionist Models. In G.D.A. Brown and N.C. Ellis (Eds.), *Handbook of spelling: Theory, process and intervention, (pp. 337-364).* Chichester, UK: John Wiley.

Ormrod, J.E. (1986). Difference between good and poor spellers in reading style and short-term memory. *Visible Language, 20(4),* 437-447.

Ormrod, J.E., and Cochran, K.F. (1988). Relationship of verbal memory and working memory to spelling achievement and learning to spell. *Reading Research and Instruction, 28(1),* 33-43.

Orton, S.T. (1937). *Reading, writing and speech problems in children.* New York: W.W. Norton.

O'Sullivan, O., and Thomas, A. (2007). *Understanding spelling.* Oxon: Routledge.

Otaiba, S.A., and Fuchs, D. (2006). Who are the young children for who best practices in reading are ineffective? An experimental and longitudinal study. *Journal of Learning Disabilities, 39(5),* 414-431.

Owen, A.M., Evans, A.C., and Petrides, M. (1996). Evidence for a two-stage model of spatial working memory processing within the lateral frontal cortex: A positron emission tomography study. *Cerebral Cortex, 6(1),* 31–38.

Palmer, S. (2000). Phonological recoding deficit in working memory of dyslexic teenagers. *Journal of Research in Reading, 23(1),* 28-40.

Palmer, S. (2000a). Working memory: A developmental study of phonological recoding. *Memory, 8(3),* 179-193.

Palmer, S. (2000b). Development of phonological recoding and literacy acquisition: a four-year cross-sequential study. *British Journal of Developmental Psychology, 18(4),* 533-555.

Patterson, K. (1986). Lexical but nonsemantic spelling. *Cognitive Neuropsychology, 3(3),* 341-367.

Pattison, H.H., and Collier, J. (1992). Methodological issues in the investigation of spelling and spelling development. In C.M. Sterling and C. Robson (Eds.), *Psychology, Spelling and Education.* Clevedon, UK: Multilingual Matters Ltd.

Pavio, A. (1969). Mental imagery in associative learning and memory. *Psychological Review, 76(3),* 241-263.

Penney, C.G. (1989). Modality effects and the structure of short-term verbal memory. *Memory and Cognition, 17(4),* 398-422.

Pennington, B.F., Cardoso-Martins, C., Green, P.A., and Lefly, D.L. (2001). Comparing the phonological and double deficit hypotheses for developmental dyslexia. *Reading and Writing, 14(7-8),* 707–755.

Perfetti, C. A., Beck, L, Bell, L., and Hughes, C. (1987). Phonemic knowledge and learning to read are reciprocal: A longitudinal study of first grade children. *Merrill-Palmer Quarterly, 33(3),* 283-319.

Peters, M. (1985). *Spelling, caught or taught? A new look.* London: Routledge and Kegan Paul.

Pickering, S. (2001). The development of visuo-spatial working memory. *Memory, 9 (4/5/6/),* 423-432.

Pickering, S., (2004). Verbal memory in the learning of literacy. In M. Turner and J. Rack, (Eds.), *The Study of Dyslexia (pp. 131-156).* New York: Plenum Publishers.

Pickering, S. (2006). Assessment of working memory in children. In S. Pickering (Ed.), *Working memory and education (pp. 241-271).* London: Academic Press.

Pickering, S., and Gathercole, S. (2001). *The working memory test battery for children.* London: The Psychological Corporation.

Pickering, S. J., Gathercole, S. E., Hall, M., and Lloyd, S. A. (2001). Development of memory for pattern and path: Further evidence for the fractionation of visual and spatial short-term memory. *Quarterly Journal of Experimental Psychology: A*, 54(2), 397–420.

Portrat, S., Camos, V., and Barrouillet, P. (2009). Working memory in children: A time-constrained functioning similar to adults. *Journal of Experimental Child Psychology 102(3)*, 368–374

Prabhakaran, V., Narayanan, K., Zhao, Z., and Gabrieli, J.D.E. (2000). Integration of diverse information in working memory within the frontal lobe. *Nature Neuroscience, 3(1),* 85-90.

Quinn, J. G., and McConnell, J. (1996). Irrelevant pictures in visual working memory. *Quarterly Journal of Experimental Psychology A, 49(1),* 200-215.

Raaijmakers, J.G.W., and Shiffrin, R.M. (1981). Search of associative memory. *Psychological Review, 88(2),* 454-457.

Rack, J.P. (1985). Orthographic and phonetic coding in developmental dyslexia. *British Journal of Psychology, 76(3),* 325-340.

Rack, J.P., Snowling, M.J., and Olson, R.K. (1992) The nonword reading deficit in developmental dyslexia: a review. *Reading Research Quarterly, 27(1),* 29-53.

Rapala, M.C., and Brady, S. (1990). Reading ability and short-term memory: The role of phonological processing. *Reading and Writing: An Interdisciplinary Journal, 2(1),* 1–25.

Rapp, B., and Caramazza, A. (1993). On the distinction between deficits of access and deficits of storage: A question of theory. *Cognitive Neuropsychology, 10(2),* 113–141.

Rapp, B., Epstein, C., and Tainturier, M. J. (2002). The integration of information across lexical and sublexical processes in spelling. *Cognitive Neuropsychology, 19(1),* 1–29.

Read, C. (1975). *Children's categorisation of speech sounds in English. NCTE Research Report No. 17.* Urbana, Illinois: National Council of Teachers of English.

Read, C. (1986). *Children's creative spelling.* London: Routledge Kegan Paul.

Repovš, G., and Baddeley, A.D. (2006). The multi-component model of working memory: Explorations in experimental cognitive psychology. *Neuroscience, 139(1),* 5-21.

Rieth, H., Axelrod, S., Anderson, R., Hathaway, F., Wood, K., and Fitzgerald, C. (1974). Influence of distribution of practice and daily testing on weekly spelling tests. *Journal of Educational Research, 68(2),* 73-77.

Rittle-Johnson, B., and Siegler, R.S. (1999). Learning to spell: Variability, choice, and change in children's strategy use. *Child Development, 70(2),* 332-348.

Robson, C. (2002). *Real world research* (2nd edition). Oxford, UK: Blackwell Publishers.

Roeltgen, D.P., and Rapcsak, S.Z. (1993). Acquired disorders of writing and spelling. In G. Blankan, J. Dittman, H. Grimm, J. C. Marshall and C. W. Wallesch (Eds.), *Linguistic Disorders and Pathologies: An international handbook (pp. 262-278).* Berlin: New York: Walter de Gruyter, Inc.

Roeltgen, D.P., Sevush, S., and Heilman, K.M. (1983). Phonological agraphia, writing by the lexical semantic route. *Neurology, 33(6),* 755-765.

Rohl, M., and Pratt, C. (1995). Phonological awareness, verbal working memory and the acquisition of literacy. *Reading and Writing: An Interdisciplinary Journal, 7(4),* 327-360.

Royal Mail. (2005). *Poor communication costs UK businesses billions in lost sales.* Available at: http://www.news.royalmailgroup.com/news/articlea.asp?id=1559andbrand=royal_mail

Rudner, M., and Rönnberg, J. (2008). The role of the episodic buffer in working memory for language processing. *Cognitive Processing, 9(1),* 19-28.

Rumelhart, D.E., Hinton, G.E., and Williams, R.J. (1986). Learning representations by back-propagating errors. *Nature, 323,* 533 – 536.

Sacre, L., and Masterson, J. (2000) *Single Word Spelling Test.* London: nferNelson.

Sadoski, M., and Paivio, A. (2004). A dual coding theoretical model of reading. In R. B. Ruddell and N. J. Unrau (Eds.), *Theoretical models and processes of reading (5th ed.) (pp. 1329-1362).* Newark, DE: International Reading Association. Available at: http://www.wolfsonian.fiu.edu/education/litsymp/pdf/sadoski_reading.pdf

Sadoski, M., Willson, V., Holcomb, A., and Boulware-Gooden, R. (2004). Verbal and nonverbal predictors of spelling performance. *Journal of Literacy Research, 36(4),* 461–478.

Salamé, P, and Baddeley, A.D. (1990). The effects of irrelevant speech on immediate free recall. *Bulletin of the Psychonomic Society, 28(6),* 540-542.

Salthouse, T.A. (2005). Relations between cognitive abilities and measures of executive functioning. *Neuropsychology, 19(4),* 532-545.

Savage, R.S., and Frederickson, N. (2006). Beyond phonology: What else is needed to describe the problems of below-average readers and spellers? *Journal of Learning Disabilities, 39(5),* 399-413.

Savage, R.S., Frederickson, N., Goodwin, R., Patni, U., Smith, N., and Tuersley, L. (2005). Relationships among rapid digit naming, phonological processing, motor automaticity, and speech perception in poor, average, and good readers and spellers. *Journal of Learning Disabilities, 38(1),* 12-28.

Savage, R., Lavers, N., and Pillay, V. (2007). Working memory and reading difficulties: What we know and what we don't know about the relationship. *Educational Psychology Review, 19(2),* 185-221.

Savage, R., Pillay, V., and Melidona, S. (2008). Rapid serial naming is a unique predictor of spelling in children. *Journal of Learning Disabilities, 41(3),* 235-250.

Scarborough, H.S. (1990). Very early language deficits in dyslexic children. *Child Development, 61(6),* 1728–1743.

Scarborough, H.S. (1998). Predicting the future achievement of second graders with reading disabilities: Contributions of phonemic awareness, verbal memory, rapid naming, and IQ. *Annuals of Dyslexia, 48(1),* 115-136.

Schlagal, B. (2001). Traditional, developmental, and structured language approaches to spelling: Review and recommendations. *Annuals of Dyslexia, 51(1),* 147-176.

Schoephoerster, H. (1962). Research into variations of the test-study plan of teaching spelling. *Elementary English, 39,* 460-462.

Schramm, R.M., and Dortch, R.N. (1991, Sept.). An analysis of effective resume content, format, and appearance based on college recruiter perceptions. *Business Communication Quarterly, 54(3),* 18–23.

Scoville, W.B., and Milner, B. (1957). Loss of recent memory after bilateral hippocampal lesions. *Journal of Neurology, Neurosurgery, and Psychiatry, 20(1),* 11–21.

Scott, C.M. (2000). Principles and methods of spelling instruction: Applications for poor spellers. *Topics on Language Disorders, 20(3),* 66–82.

Scottish Executive Education Department (SEED), (2006). *Education in Scotland.* Available at: http://www.scotland.gov.uk/Publications/2006/06/22092946/0

Seidenberg, M.S., and McClelland., J.L. (1989). A distributed, developmental model of word recognition and naming. *Psychological Review, 96(4),* 523-568.

Service, E., and Turpeinen, R. (2001). Working memory in spelling: Evidence from backward typing. *Memory, 9(4/5/6),* 395-421.

Shah, P., and Miyake, A. (1996). The separability of working memory resources for spatial thinking and language processing: An individual differences approach. *Journal of Experimental Psychology: General, 125(1),* 4–27.

Shallice, T. (1981). Phonological agraphia and the lexical route in writing. Brain, 104(3), 413–429.

Share, D.L. (1995). Phonological recoding and self-teaching: sine qua non of reading acquisition. Cognition, 55(2), 151-218.

Shankweiler, D., Crain, S., Brady, S., and Macaruso, P. (1992). Identifying the causes of reading disability. In P.B. Gough, L.C. Ehri., and R. Treiman, (Eds.), *Reading Acquisition, (pp. 275-305).* Hillsdale, NJ: Lawrence Erlbaum Associates.

Siegel, L.S. (1994). Working memory and reading: A life-span perspective. *International Journal of Behavioral Development, 17(1),* 109–124.

Siegel, L.S., and Ryan, E.B. (1989). The development of working memory in normally achieving and subtypes of learning disabled children. *Child Development, 60(4),* 973–980.

Smith, F. (1982). *Writing and the writer.* New York: Holt, Rinehart and Winston.

Smith, M.K. (2005). Development of visual-verbal integration in working memory and its relation to language and reading abilities. *Unpublished Doctoral Dissertation,* Georgia State University. Available at: http://etd.gsu.edu/theses/available/etd-03282005-152633/unrestricted/smith_m_katrina_200505_phd.pdf

Smith, E.E., and Jonides, J. (1997). Working memory: A view from neuroimaging. *Cognitive Psychology, 33(1),* 5–42.

Snowling, M (1994). Towards a model of spelling acquisition: The development of some component skills. In G.D.A. Brown and N.C. Ellis (Eds.), *Handbook of* *spelling: Theory, process and intervention (pp. 111-128).* Chichester, England: John Wiley and Sons.

Snowling, M.J. (2000). *Dyslexia.* Oxford: Blackwell.

Snowling, M.J., and Stackhouse, J. (Eds.) (2006). *Dyslexia, speech and language (2nd edition).* London: Whurr.

Snowling, M.J., Chiat, S., and Hulme, C. (1991). Words, nonwords, and phonological processes: Some comments on Gathercole, Willis, Emslie, and Baddeley. *Applied Psycholinguistics, 12(3),* 369-373.

St Clair-Thompson, H. L., and Gathercole, S. E. (2006). Executive functions and achievements on national curriculum tests: Shifting, updating, inhibition, and working memory. *Quarterly Journal of Experimental Psychology, 59(4),* 745-759.

Strattman, K., and Hodson, B.W. (2005). Variables that influence decoding and spelling in beginning readers. *Child Language and Therapy, 21(2),* 165–190.

Strauss, E., Sherman, E.M.S., and Spreen, O. (2006). *A compendium of neuropsychological tests.* New York: Oxford University Press.

Stuart, M. and Dixon, M. (2000). Spongelike acquisition of sight vocabulary in beginning readers? *Journal of Research in Reading, 23(1)*, 12-27.

Stuart, M. and Masterson, J. (1992) Patterns of reading and spelling in 10-year-old children related to prereading phonological abilities. *Journal of Experimental Child Psychology, 54(2),* 168-87.

Sunseth, K., and Bowers, G.B. (2002). Rapid naming and phonemic awareness: Contributions to reading, spelling and orthographic knowledge. *Scientific Studies of Reading, 6(4),* 401–429.

Swan, D., and Goswami, U. (1997). Phonological awareness deficits in developmental dyslexia and the phonological representations hypothesis. *Journal of Experimental Child Psychology, 66(1),* 18-41.

Swanson, H.L., and Ashbaker, M. (2000). Working memory, STM, articulation speed, word recognition, and reading comprehension in learning disabled readers: Executive and/or articulatory system? *Intelligence, 28(1),* 1–30.

Swanson, H.L., and Jerman, O. (2007). The influence of working memory on reading growth in subgroups of children with reading disabilities. *Journal of Experimental Child Psychology, 96(4),* 249-283.

Swanson, H.L., and Siegel, L. (2001). Learning disabilities as a working memory deficit. *Issues in Education, 7(1),* 1-49.

Swanson, H.L., Hoskyn, M.W., and Lee, C. (1999). *Interventions for students with learning disabilities: A meta-analysis of treatment outcomes.* New York: Guilford Press.

Tabachnick, B.G., and Fidell, L.S. (1996). *Using multivariate statistics.* New York: HarperCollins.

Tainturier, M. J. and Rapp, B. C. (2004). Complex Graphemes as Functional Spelling Units: Evidence from Acquired Dysgraphia. *Neurocase, 10(2),* 122-131.

Tallal, P., Miller, S.L., Jenkins, W.M., and Merzenich, M.M. (1997). The role of temporal processing in developmental language-based learning disorders. In B.A. Blachman (Ed.), *Foundations of reading acquisition and dyslexia: Implications for early intervention (pp. 49-66).* Mahwah, New Jersey: Lawrence Erlbaum Associates.

Templeton, S. (1991). Teaching and learning the English spelling system: Re-conceptualizing method and purpose. *The Elementary School Journal, 92(2),* 185-201.

Templeton, S., and Bear, D. (Eds.) (1992). *Development of orthographic knowledge and the foundations of literacy: A memorial festschrift for Edward H. Henderson.* Hillsdale, NJ.: Lawrence Erlbaum Associates.

Tenney, Y.J. Visual factors in spelling. In U. Frith (Ed.), *Cognitive Processes in Spelling (pp. 215-229).* London: Academic Press.

The University of Nottingham (press release). (2006). *Survey reveals literacy problem for business.* Available at: http://www.nottingham.ac.uk/public-affairs/press-releases/index.phtml?menu=pressreleasesarchiveandcode=SUR-208/06andcreate_date=06-dec-2006

Thomson, M. (1988). Preliminary findings concerning the effects of specialised teaching on dyslexic children. *Applied Cognitive Psychology, 2(1),* 19-31.

Thomson, M. (1991). The teaching of spelling using techniques of simultaneous oral spelling and visual inspection. In M. Snowling and M Thompson (Eds.), *Dyslexia: Integrating Theory and Practice (pp. 244-250).* London: Whurr.

Thorn, A., and Page, M. (Eds.). (2009). *Interactions between short-term and long-term memory in the verbal domain.* Hove, East Sussex, UK: Psychology Press.

Tijms, J. (2004). Verbal memory and phonological processing in dyslexia. *Journal of Research in Reading, 27(3),* 300-310.

Torgesen, J.K.(1980). The use of efficient task strategies by learning disabled children: Conceptual and educational implications. *Journal of Learning Disabilities, 13(7),* 364-371.

Torgesen, J. K. (2000). Individual differences in response to early interventions in reading: The lingering problem of treatment resistors. *Learning Disabilities Research and Practice, 15(1),* 55-64.

Torgesen, J. K. and Houck, D. G. (1980). Processing deficiencies of learning-disabled children who perform poorly on the digit span test. *Journal of Educational Psychology, 72(2),* 141--160.

Torgesen, J.K., Wagner, R.K., Rashotte, C.A., Burgess, C. and Hecht, S. (1997). Contributions of phonological awareness and rapid automatic naming ability to the growth of word-reading skills in second- to fifth-grade children. *Scientific Studies of Reading, 1(2),* 161–185.

Torgesen, J.K., Alexander, A.W., Wagner, R.K., Rashotte, C.A., Voeller, K.K.S., and Conway, T. (2001). Intensive Remedial Instruction for Children with Severe Reading Disabilities: Immediate and Long-Term Outcomes from Two Instructional Approaches. *Journal of Learning Disabilities, 34(1),* 33-58.

Tornéus, M. (1984). Phonological awareness and reading: A chicken and egg problem? *Journal of Experimental Child Psychology, 76(5),* 1346-1358.

Towse, J. N., and Hitch, G. J. (1995). Is there a relationship between task demand and storage space in tests of working memory capacity? *Quarterly Journal of Experimental Psychology A, 48(1),* 108–124.

Treiman, R. (1997). Spelling in Normal Children and Dyslexics. In E. Blachman, (Ed.), *Foundations of Reading Acquisition and Dyslexia, (pp. 191-228).* Mahwah, New Jersey: Lawrence Erlbaum Publishers.

Treiman, R. and Baron, J. (1983). Individual differences in spelling: The Phoenician-Chinese distinction. *Topics in Learning and Learning Disabilities, 3(2),* 33-40.

Treiman, R., and Bourassa, D.C. (2000). The development of spelling skill. *Topics in Language Disorders, 20(3),* 1-18.

Treiman, R., Cassar, M., and Zukowski, A. (1994). What types of linguistic information do children use in spelling? The case of flaps. *Child Development, 65(5),* 1318-1317.

Tsesmeli, S.N., and Seymour, P.H.K. (2006). Derivational morphology and spelling in dyslexia. *Reading and Writing: An Interdisciplinary Journal, 19(6),* 587-625.

Uhry, J. K. and Shepherd, M. J. (1993). Segmentation and spelling instruction as part of a first-grade reading program: Effects on several measures of reading. *Reading Research Quarterly, 28(3),* 219-233.

Vallar, G. (2006). Mind, Brain and Functional Neuroimaging, *Cortex, 42(3),* 402-405.

Vallar, G., and Papagno, C. (2002). Neuropsychological impairments of verbal short-term memory. In M. Kopelman, A.D. Baddeley, and B. Wilson (Eds.), *Handbook of neuropsychology (2nd ed., pp. 249–270).* Chichester, England: Wiley.

Van Oudenhoven, J.P., Van Berkum, G., and Swen-Koopmans, T. (1987). Effect of cooperation and shared feedback on spelling achievement. *Journal of Educational Psychology, 79(1),* 92-94.

Varnhagen, C.K., McCallum, M., and Burstow, M. (1997). Is children's spelling naturally stage-like? *Reading and Writing: An interdisciplinary Journal, 9(5/6),* 451-481.

Vaughn, S., Schumm, J., and Gordon, J. (1993). Which motoric condition is most effective for teaching spelling to students with and without learning disabilities? *Journal of Learning Disabilities, 26(3),* 191-198.

Vellutino, F. R., and Scanlon, D. M. (1987). Phonological coding, phonological awareness, and reading ability: Evidence from a longitudinal and experimental study. *Merrill-Palmer Quarterly, 33(3),* 321–363.

Vellutino, F.R., Fletcher, J.M., Snowling, M.J., and Scanlon, D.M. (2004). Specific reading disability (dyslexia): what have we learned in the past four decades? *Journal of Child Psychology and Psychiatry, 45(1),* 2 – 40.

Venezky, R. L. (1967). English orthography: Its graphical structure and its relation to sound. *Reading Research Quarterly, 2(3),* 75-105.

Venezky, R. L. (1980). Spelling instruction and spelling reforms. In U. Frith (Ed.), *Cognitive Processes in Spelling (pp. 9-30).* London: Academic Press.

Verhaeghen, P., Cerella, J., and Basak, C. (2004). A working memory workout: how to expand the focus of serial attention from one to four Items in 10 hours or less. *Journal of Experimental Psychology: Learning Memory and Cognition, 30(6),* 1322-1336.

Wagner, R.K., and Torgesen, J.K. (1987). The nature of phonological processing and its causal role in the acquisition of reading skills. *Psychological Bulletin, 101(2),* 192-212.

Wagner, R. K., Torgesen, J. K., and Rashotte, C. A. (1994). Development of reading-related phonological processing abilities: New evidence of bidirectional causality from a latent variable longitudinal study. *Developmental Psychology, 30(1),* 73-87.

Wagner, R.K., Torgesen, J.K., Laughon, P., Simmons, K., and Rashotte, C.A. (1993). Development of young readers' phonological processing abilities. *Journal of Educational Psychology, 85(1),* 83–103.

Wagner, R.K., Torgesen, J.K., Rashotte, C.A., Hecht, S.A., Barker, T.A., Burgess, S.R., Donahue, J., and Garon, T. (1997). Changing relations between phonological processing abilities and word-level reading as children develop from beginning to skilled readers: A 5-year longitudinal study. *Developmental Psychology, 33(3),* 468-479.

Wanzek, J., Vaughn, S., Wexler, Jade; Swanson, E.A., Edmonds, M., and Kim, A-H. (2006). A synthesis of spelling and reading interventions and their effects on the spelling outcomes of students with LD. *Journal of Learning Disabilities, 39(6),* 528-543.

Waters, G. S., and Caplan, D. (1996). The measurement of verbal working memory capacity and its relation to reading comprehension. *Quarterly Journal of Experimental Psychology:A, 49(1),* 51–79.

Waters, G.S., Bruck, M., and Seidenberg, M. (1985). Do children use similar processes to read and spell words? *Journal of Experimental Child Psychology, 39(3),* 511-530.

Weeks, S., Brooks, P., and Everatt. (2002). Differences in learning to spell: Relationships between cognitive profiles and learning responses to teaching methods. *Educational and Child Psychology, 19(4),* 47-62.

Weiner, B. (1979). A theory of motivation for some classroom experiences. *Journal of Educational Psychology,* 71(1), 3-25.

Westwood, P. (2008). *What teachers need to know about spelling.* Camberwell, Victoria: ACER Press.

Wickelgren, W.A. (1969). Short-term memory for phonemically similar lists. *American Journal of psychology, 78(4),* 567-574.

Wilson, J. T. L., Scott, J. H., and Power, K. G. (1987). Developmental differences in the span of visual memory for pattern. *British Journal of Developmental Psychology, 5(3),* 249-255.

Wimmer, H. (1993). Characteristics of developmental dyslexia in a regular writing system. *Applied Psycholinguistics, 14(1),* 1–33.

Wimmer, H., Mayringer, H., and Landerl, K. (1998). Poor reading: A deficit in skill automatization or a phonological deficit? *Scientific Studies of Reading, 2(4),* 321–340.

Winch, C., and Wells, P. (1995). The quality of student writing in higher education: A cause for concern? *British Journal of Educational Studies. 43(1),* 75-87.

Wing, A. M., and Baddeley, A. D. (1980). Spelling errors in handwriting: A corpus and distributional analysis. In U. Frith (Ed.), *Cognitive Processes in Spelling (pp. 251-285).* London: Academic Press.

Wolf, M., and Bowers, P.G. (1999). The double deficit hypothesis for the developmental dyslexias. *Journal of Educational Psychology, 91(3),* 415-438.

Wolf, M., Bowers, P.G., and Biddle, K. (2000). Naming speed processes, timing, and reading: A conceptual review. *Journal of Learning Disabilities, 33(4),* 387-407.

Yopp, H. K. (1988). The validity and reliability of phonemic awareness tests. *Reading Research Quarterly, 23(2),*159–177.

Zhang, D. R., Zhang, X., Sun, X., Li, Z., He, S., and Hu, X. (2004). Cross-modal temporal order memory for auditory digits and visual locations: an fMRI study. *Human Brain Mapping, 22(4),* 280-289.

Ziegler, J.C., Stone, G.O., and Jacobs, A.M. (1997). What is the pronunciation for -ough and the spelling for /u/? A database for computing feedforward and feedback consistency in English. *Behaviour Research Methods, Instruments, and Computers, 29(4),* 600-618.

Zutell, J. (1978). Spelling strategies of primary school children and their relationship to Piaget's concept of decentration. *Unpublished doctoral dissertation*, University of Virginia, Charlottesville.

APPENDIX A: DEMOGRAPHIC PROFILES OF SCHOOLS

School	Roll	No. free school meals 08/09	No. free school meals 07/07	Attendance 07/08
A	256	50	53	93
B	195	27	24	96
C	347	70	76	95
D	132	74	65	93

APPENDIX B: CONSENT LETTER

PARENT/GUARDIAN
ADDRESS1
ADDRESS2
POSTCODE
Dear PARENT/GUARDIAN
Re: Permission to ask your child to take part in a spelling project.
I am an educational psychologist with the Renfrewshire Educational Psychology Service and I'm helping to organise a project in which your child's class and teacher will be taking part . The main aim of the project is to look for ways to support children in learning to spell. The project meets with Renfrewshire Council's aim to improve learning and teaching and has the Council's full approval.
The project will be in two parts. The first will look into the connection between working memory and spelling. The second will compare two different methods for learning to spell words. Details of each part are enclosed on a separate sheet.
The project will be explained fully to the children before it begins and also again at the start of both parts so that they know what to expect. The children will be told that taking part is entirely their choice and that they will not be held to account if they don't want to take part at any stage. The children will also be offered the opportunity to discuss any questions they may have with either the class teacher or with myself.
All information collected will be treated with full confidentiality. Once the project has been completed, feedback will be offered to schools and parents. The results will be written up in a report. However, all information will be anonymous and it will not be possible to identify individuals or schools.
Your cooperation with this would be greatly appreciated. If you agree for CHILD'S_NAME to be asked to take part in this project I would be grateful if you would sign the attached tear off slip and ***return it with your child to the class teacher****. If you have any questions about this research, please do not hesitate to contact me at the number above.*
Yours sincerely
Vivien Yih
Educational Psychologist

✂---

CONSENT FORM
I agree for my child to be asked to take part in this spelling project in SCHOOL Primary School.
I understand that confidentiality is assured. I have been informed that all participation in this project is entirely voluntary.
I understand that my child can withdraw at any time during the project.
Child's Name ______________________________
Parent's Name ____________________________
Signed __________________________________

THE PROJECT

The project will be in two parts.

Part 1: *For each pupil, this will involve taking part in:*

a) A whole class spelling test administered by the class teacher, lasting approximately 30 minutes.

b) One-to-one testing by the researcher using some short working memory tests. This will last approximately 10-15 minutes for each pupil.

Part 1 is expected to take place during November- December of this year.

Part 2: *The training will be given to groups of children in each class and will last for three weeks. The words will be chosen by the teacher and researcher. The groups for training will also be chosen by the teacher and will be all the children whose spelling levels are within the normal range as well as those who are struggling with spelling. In the first week, the children will be given a number of words and asked to learn them. No specific training will be given. The second week children will learn another group of words using the 'Look, Cover, Write, Check' method. In the final week, a set of words will be taught using the 'Simultaneous Oral Spelling' method.*

The children will be tested on the words at the end of each week, one week later, and two weeks later following each learning condition.

This part is expected to take place during March – April 2008.

APPENDIX C. CONTENTS OF SPELLING PACK

Teacher use

1. At-a-glance spelling intervention timetable (blue).
2. Instructions for introduction /pre-test and training weeks 1-3 (green).
3. Spelling pre-test (orange).
4. Observation checklists (yellow).
5. Pupil record sheet (pink).
6. Summary of words for training (purple).
7. A4 sheet of card for covering up words on board.

Pupil use (all white)

1. Response sheets for pre-test.
2. Pupil practice sheets for sets 1, 2 and 3.
3. White strips of card for covering words.

Spelling Study Timetable - PART TWO

		MON	TUE	WED	THU	FRI
	APR/MAY Wk/Bg 28th	28. Intro (see instructions). GIVE PRE-TEST. Pupils can be tested later in the week if absent today.	29	30	1	2
Week 1	MAY Wk/Bg 5th Untrained condition	Pub Hol 5	6 Give set __. (See instructions)	7 Individual study	8 Individual study	9 Test set __.
Week 2	MAY Wk/Bg 12th SACAWAC	12. Teach method and SACAWAC (script) Give set ___. Do first word.	13. Review method. Do another three words (2,3,4).	14. Review method Do another three words (5,6,7).	15. Review method Do another three words (8,9,10). Revise words 1-7 by writing once.	16. Test set ____
Week 3	MAY Wk/Bg 19th SOS	19. Teach method and SOS (script). Give set ___. Do first word.	20. Review method. Do another three words (2,3,4).	21. Review method. Do another three words (5,6,7).	22. Review method. Do another three words (8,9,10).Revise words 1-7 by writing once. (AM) TEST IN AFTERNOON	23. INSET
Week 4	MAY Wk/Bg 26th **Retest set __**	Pub Hol 26	27	28	29. Retest set __ today or tomorrow	30.
Week 5	JUN Wk/Bg 2nd **Retest set __**	2	3	4	5. Retest set __ today or tomorrow	6
Week 6	JUN Wk/Bg 9th **Retest set __**	9	10	11	12 Retest set __ today or tomorrow	

APPENDIX E: INSTRUCTIONS FOR INTRODUCTION AND PRETEST

Introduction

Script:

This term, we are going to start the second part of the spelling study you began last session. Starting next week for the next three weeks, you are going to be given a set of words to learn. You will get a new set of words each week and you will learn the words in a different way each week. We want to find out which way was the best in helping you to learn the words. Each week, you will get the words on Monday (or Tuesday, if Monday's a holiday), learn them during the week, and get a test of the words on Friday. In the second and third week, I will teach you a way to learn the words. But in the first week, I'm not going to tell you how to learn them. Just do it any way you like – I'll leave it up to you. Just do what you normally do.

This week, you will not be learning any of the words. But today you are going to have what we call a PRETEST of the words. I am going to tell you the words you will be learning during the three week and you will write them down. Now - these words are very hard and you are not expected to know how to spell them. You haven't learned them yet so don't worry about making mistakes. There are thirty words in total. We need to do this to find out how many of these words you can already spell.

The Pre-Test

Materials available:

- Test sheet with words and sentences.
- Pupil response sheets.
- Summary score sheet for class.

Give the pupils the pre-test. When you have finished, collect in the tests, score them, and record scores on the class answer sheet. The pupils must not correct them. Try to discourage any learning of the words as this could interfere with the results of the later training.

APPENDIX F: TEACHER INSTRUCTIONS FOR WEEK 1

Week 1 - (Wk/Bg 5th May – Monday holiday)

No training condition.

Materials needed:

- Pupil practice sheets with words to be learned for set _____

On Tuesday the teacher gives out the practice sheet for set ______ and explains what to do (see below). At the end of the spelling practice time (15 minutes) the papers are collected in and given out again the next day. Pupils study the words on their own on Tuesday, Wednesday and Thursday and are tested on Friday.

The teacher explains what to do using the script.

Script.
Here are the words to be learned for this week. You will have 15 minutes to practise the words each day (Tuesday, Wednesday and Thursday). On Friday you will be given a test on the words. DO NOT WORRY about the test. Just do the best you can. These words are quite hard. You can learn them any way you like. I suggest you learn three or four each day. You must do this on your own. You can use the space beneath the words to copy the letters out if you wish. You can start now. If you feel you have learned three words before the 15 minutes is over let me know.

Observe the pupils as they work using observation sheet. You are allowed to help by answering questions, e.g. how to say the word, what it means, general instructions but do not help them to study the words or suggest ways to do this except what is written in the script.

There are no prepared sheets for pupil end of week tests. Please use any ordinary paper but keep all papers. Allow pupils to mark another pupil's paper and then collect them in. Please stress the importance of not changing anything when correcting.

APPENDIX G: TEACHER INSTRUCTIONS FOR WEEK 2

Week 2 (Wk/Bg 12th May).

SACAWAC method (look /say and cover and write and check).

Materials needed

- Pupil practice sheets with words to be learned for set _____
- White card strips to cover up the words.
- Blackboard/ whiteboard for demonstration and one A4 card.

Monday

1. Give out practice sheets for set ________. Tell pupils to put them aside for now.
2. Teach the SACAWAC method using instructions below.
3. At the end of the demonstration write the words LOOK, SAY, COVER, WRITE, CHECK on the board for the pupils to consult.
4. Pupils then practise the method using the first word of the set.
5. Use the observation checklist to monitor while pupils work. You can also help pupils with the method.

Instructions

Use the word VOICE to teach the SACAWAC method. Write the word on the board to demonstrate the method. Point to the word on the board and say this is just a practice word, not one of their training words.

Begin the instructions.

1. This method is called the SACAWAC method.
2. First you LOOK at your word carefully. Can you see any patterns or groups of letters that go together? Are there any words within the word?
3. Next you SAY the word out loud.
4. Next you COVER the word with your card by placing along top of the paper (hold up a practice sheet and put the card over the top to demonstrate and then continue the blackboard demonstration by covering the word on the board with the large card).
5. Next you WRITE the word underneath (write the word underneath).
6. Then you take the card away and CHECK the word is correct. If you get the word wrong then just put a line through it and try again underneath.
7. REPEAT these steps until you have written the word correctly three times.

Tuesday and Wednesday.

1. Give out practice sheets.
2. Aim for pupils to do about three words a day.

Thursday

1. Pupils do the last three words and then write all the previous words again once using the SACAWAC method.

Friday

1. Test the pupils on the words.
2. Each pupil to correct another's paper and then collect in. Check and record scores.

APPENDIX H: TEACHER INSTRUCTIONS FOR WEEK 3

Week 3 (Wk/Bg 19th May). SOS method (Simultaneous oral Spelling)

Materials needed

- Pupil practice sheets with words to be learned for set _____
- White card strips to cover up the words.
- Blackboard/ whiteboard for demonstration and one A4 card.

Monday

1. Give out practice sheets for set ________. Tell pupils to put them aside for now.
2. Teach the SOS method using the instructions below. Write the word on the board and tell pupils that this method is very like the one they used last week with only one difference. Show them how to use the method.
3. At the end of the demonstration write the words LOOK, SAY, COVER, WRITE AND NAME EACH LETTER AS YOU WRITE, CHECK on the board for the pupils to consult.
4. Pupils then practise the method using the first word of the set.
5. Use the observation checklist to monitor while pupils work. You can also help pupils with the method.

Instructions
Use the word MATCH to teach the SOS method.
Write the word on the board to demonstrate the method. Point to the word on the board and say this is just a practice word, not one of their training words.
Begin the instructions.
1. This method is called simultaneous oral spelling (SOS).
2. First you LOOK at your word carefully as before, looking for any letter patterns.
3. Next you SAY the word out loud.
4. Next you COVER the word with your card by placing along top of the paper as you did before.
5. Next you WRITE the word underneath SAYING EACH LETTER NAME OUT LOUD AS YOU WRITE (stress this as you demonstrate).
6. Then you take the card away and CHECK the word is correct. If you get the word wrong then just put a line through it and try again underneath.
7. REPEAT these steps until you have written the word correctly three times.
(You may want to suggest to the pupils that they to say the letters names out quietly to themselves.)

Tuesday and Wednesday.

1. Give out practice sheets.
2. Aim for pupils to do about three words a day.

Thursday

Pupils do the last three words and then write all the previous the words again once using the SOS method.

Friday

1. Test the pupils on the words.
2. Each pupil to correct another's paper and then collect in. Check and record scores.

APPENDIX I: SPELLING PRE-TEST

	WORD	Sentences	WRITE
1	measured	The nurse measured my height.	measured
2	dangerous	It is dangerous to swim in this river.	dangerous
3	chemist	We can get our medicine from the chemist.	chemist
4	elephant	We saw an elephant in the safari park.	elephant
5	enough	There were enough sweets for everyone to have one.	enough
6	journey	The journey was very long.	journey
7	division	The division sum was very hard.	division
8	scenery	The scenery at the lake was beautiful.	scenery
9	parties	Children's parties are lots of fun.	parties
10	quickly	She ran the race very quickly.	quickly
11	raised	We raised lots of money at the charity fair.	raised
12	marvellous	We had a marvellous time on our day trip to Edinburgh.	marvellous
13	explain	The teacher will explain what we should do.	explain
14	difference	There is not much difference between the twins.	difference
15	concert	We went to a concert in the park.	concert
16	puncture	My bicycle had a puncture.	puncture
17	permission	You need to get permission to take pictures in here.	permission
18	science	We saw a robot at the science museum.	science
19	trolleys	Supermarkets have trolleys to put your shopping into.	trolleys
20	hurried	Everyone hurried to get out of the rain.	hurried
21	caused	The heavy rain caused the river to flood.	caused
22	enormous	The elephant was enormous.	enormous
23	smudge	I made a smudge on the page with my pencil.	smudge
24	innocent	The man was found innocent of the crime.	innocent
25	laugh	The jokes in this book make me laugh.	laugh
26	attention	You need to pay attention in class.	attention
27	neighbour	My have a new neighbour next door.	neighbour
28	scissors	The scissors were too blunt to cut the cloth.	scissors
29	families	This is good park for children and their families.	families
30	practised	The band practised their new songs for the concert.	practised

APPENDIX J: PUPIL PRE-TEST RESPONSE SHEET

Pupil Response Sheet for Pre-Test

Name ____________________ Date ________________

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Total ☐

APPENDIX K: SUMMARY OF WORDS FOR TRAINING

Words for Training

Set 1	**Set 2**	**Set 3**
measured	Raised	caused
dangerous	Marvellous	enormous
chemist	Explain	smudge
elephant	Difference	innocent
enough	Concert	laugh
journey	Puncture	attention
division	Permission	neighbour
scenery	Science	scissors
parties	Trolleys	families
quickly	Hurried	practised

APPENDIX L: PUPIL PRACTICE SHEET - EXAMPLE

Set 1.1 Name________________________ Class____________

1	2	3	4	5
measured	dangerous	chemist	elephant	enough

APPENDIX M: OBSERVATION CHECKLIST

Name		Week * Attendance					Using method (or)	Any comments
		Mon	Tue	Wed	Thu	Fri		

APPENDIX N: PUPIL RECORD SHEET

		Friday tests			Follow-up tests		
Name	Pre-test (30)	Wk 1 No training (10)	Wk 2 Sacawac (10)	Wk 3 SOS (10)	Wk 4 No training (10)	Wk 5 Sacawac (10)	Wk 6 SOS (10)