1-1-2006

Short-term and Working Memory in Children with Specific Language Impairment

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Citation of this paper:
Archibald, Lisa M. D., "Short-term and Working Memory in Children with Specific Language Impairment" (2006). *Communication Sciences and Disorders Publications.* Paper 1.
http://ir.lib.uwo.ca/scsdpub/1

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Thesis submitted for the Degree of Doctor of Philosophy

University of Durham, Department of Psychology

2006

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Declaration

None of the data or material contained in this these has been submitted for previous or simultaneous consideration for a degree in this or any other university.

Study 1 is reported in:

Archibald, L.M.D., & Gathercole, S.E. (in press). Short-term and working memory in Specific Language Impairment. *International Journal of Language and Communication Disorders.*

Study 2 is reported in:

Archibald, L.M.D., & Gathercole, S.E. (in press). Visuospatial immediate memory in Specific Language Impairment. *Journal of Speech, Language, and Hearing Research.*

Study 4 is reported in:

Archibald, L.M.D., & Gathercole, S.E. (in press). Nonword repetition: A comparison of tests. *Journal of Speech, Language, and Hearing Research.*

Statement of Copyright

Acknowledgements

I am grateful to so many people for their support during the preparation of this thesis: My supervisor, Susan Gathercole, whose commitment to achieving excellence in each new task has been an example to me; friends and colleagues both in Durham and at home; and the school staff and students assisting with and participating in the studies. Most particularly, I wish to express my deep and sincere gratitude to those whose unfailing love and support has made all of this possible - my family … those who had the courage to come with me, and those who had the courage to let us come.

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Abstract

Investigations of the cognitive processes underlying Specific Language Impairment (SLI) have implicated deficits in the storage and processing of phonological or verbal information. This thesis reports five studies that investigated the role of short-term and working memory in children with SLI. Study 1 demonstrated SLI deficits on measures of verbal working memory, and short-term memory for verbal but not visuospatial information. Study 2 provided evidence that children with SLI perform at age-level on visuospatial working memory measures. Study 3 demonstrated slower processing in the SLI group across domains, as well as verbal storage decrements, with the greatest deficits found for tasks tapping both of these. Study 4 found SLI deficits on measures of nonword repetition in common use, with greater impairments on the task that relied to a lesser extent on short-term memory. Study 5 established more accurate recall for multisyllabic nonwords than matched single syllable lists for all groups, although the SLI group showed different patterns of phoneme retention. It is suggested that the combination of deficits in generalized processing speed and verbal storage in SLI may be expected to have a drastic and detrimental impact on learning, and provides an account of the disorder that could encompass the range of impairments observed in SLI. The findings also suggest that factors additional to short-term memory contribute to poor nonword repetition in SLI.

Chapter 1

General Introduction

Specific Language Impairment (SLI) is a term used to describe a developmental difference in the way in which a child acquires language when no other explanatory factors are present. These children have fascinated researchers for many years for the clues they may provide about the cognitive processes involved in learning language and potential strategies for effective intervention. The functioning of the cognitive systems pertaining to immediate memory has been a matter of considerable interest in SLI research. Working memory encompassing short-term memory is a limited capacity system responsible for the simultaneous storage and manipulation of information during the performance of cognitive tasks (Baddeley, 1986). Strong links have been established between working memory and language abilities, and between limitations in working memory and language impairments. This thesis is concerned with examining in detail the immediate memory functioning of children with SLI. As an introduction to the series of studies presented in this thesis, this chapter will provide a general overview of Specific Language Impairment, working memory and its role in language learning and SLI, and current theoretical perspectives of SLI.

1.1: Specific Language Impairment

Specific Language Impairment in children is an unexpected failure to develop language at the usual rate, despite normal general intellectual abilities, sensory functions, and environmental exposure to language. These children have been variously labelled as developmentally aphasic, language-disabled, language-disordered, and more recently as SLI. The use of the term impairment – ‘diminished in quality’ – is preferred in contemporary research because it is more neutral than terms such as delayed or disordered. The word ‘specific’ is intended to reflect the disproportionate difficulty these children experience in learning language. While there are still problems with the term SLI as the subsequent review of current literature will show, SLI is the term adopted for this thesis.

SLI is a relatively common developmental pathology, estimated to occur in approximately 7% of kindergarten children (Tomblin, Records, Buckwalter, Zhang, Smith & O’Brien, 1997), and is more prevalent in males than females (e.g., Choudhury & Benasich, 2003; Flax, Realpe-Bonilla, Hirsch, Brzustowicz, Bartlett, & Tallal, 2003). There is a strong genetic component to the disorder as reflected both by the findings of positive family histories for language impairment (e.g., Choudhury & Benasich, 2003; Tomblin, 1989) and heritability estimates in twin studies (e.g., Bishop, North, & Donlan, 1995; Dale, Siminoff, Bishop, Eley, Oliver, Price, et al., 1998; Tomblin & Zhang, 1999). Generally, children with SLI have no detectable brain abnormalities (Bishop, 1987; but see Gauger, Lombardino, & Leonard, 1997; Rebolledo, Prieto, Henao, Restrepo, & Salvador, 2004), neurological conditions, or risk factors associated with their birth (Bishop, 1997a); they live in typically stimulating communicative environments (Leonard, 1987), have normal hearing and oral motor function, and generally achieve other developmental milestones as expected. It is the disproportionate difficulty learning language that distinguishes children with SLI.

For many children with SLI, deficits of language persist over time. Approximately 40 to 70% of children with early language delay will continue to have impaired language skills beyond the age of five (e.g., Dale, Price, Bishop, & Plomin, 2003; Paul, 1991, 1993; Paul & Smith, 1993; Rescorla & Schwartz, 1990; Roulstone, Peters, Glogowska, Enderby, 2003). Of those with an enduring SLI, 40 to 70% will continue to have language difficulties throughout childhood (e.g., Bishop & Edmundson, 1987; Tomblin, Zhang, Buckwalter, & O'Brien, 2003) and into adulthood (e.g., Aram, Ekelman, & Nation, 1984; Johnson, Beitchman, Young, Escobar, Atkinson, et al., 1999; Snowling, Adams, Bishop, & Stothard, 2001; Snowling, Bishop, & Stothard, 2000; Stothard, Snowling, Bishop, Chipchase, & Kaplan, 1998). Even those whose language difficulties have apparently resolved and who perform in the average range on standard language measures may still be distinguishable from age peers on some measures (Bishop, North, & Donlan, 1996; Conti-Ramsden, Botting, & Faragher, 2001; Kiese-Himmel & Kruse, 1998). It should be noted that the language skills of individuals with SLI do not remain static over time; they change and improve, but age-appropriate language skills may not be achieved. This changing nature of the language difficulty over time can present a challenge when attempting to identify and compare individuals with SLI.

One question that is currently a matter of considerable debate is whether SLI represents a categorical distinction from typical development, or the low end of the continuum of language abilities. From an evolutionary perspective, a characteristic that affects 7 % of the population is a normal variant not a disorder. Supporting this perspective are results of a recent latent class analysis of the language skills of a large sample of 3- and 4-year-old children indicating dimensional distribution of language skills with no indication that a sugroup of children with SLI formed a qualitatively distinct group for three clinical indicators, receptive vocabulary, mean length of utterance, and mean number of different words (Dollaghan, 2004). In other studies (e.g., Bishop, 1994; Bishop, Bishop, Bright, James & Tallal, 1999; Tomblin & Zhang, 1999), performance of children defined as SLI has been found to be similar to children whose impairments are not specific to the language domain (nonspecific language impairment; NLI) on a number of measures. One study, however, has provided evidence of qualitative differences in grammatical tense impairments for SLI as compared to NLI groups (Rice, Tomblin, Hoffman, Richman, & Marquis, 2004). Although it is clear that further research is needed in this area, many researchers believe that a focus on children demonstrating a relatively specific impairment in language learning (i.e., SLI) remains a useful endeavour in understanding language learning and identifying potential intervention strategies.

1.1.1: Diagnostic criteria

Who has SLI? Much of the early work in this area was plagued by the lack of a consistent characterization of SLI making comparisons across studies difficult. More recently, diagnostic criteria have appeared in both the World Health Organization’s International Classification of Diseases (ICD-10; 1993) and the American Psychiatric Association’s Diagnostic and Statistical Manual (DSM-IV; 1994). Although some variance persists, criteria for SLI commonly employed in research studies are listed in Table 1.1, and it is clear from these that SLI is largely defined by what it is not. Specifically ruled out are cases in which another condition is present that may be the cause of the language impairment: neurological dysfunction, developmental disorders such as Autism Spectrum Disorder (ASD) or Developmental Delay, hearing impairment, or oral structure or motor anomalies. Although SLI may co-occur with such conditions and dual diagnoses of SLI with another disorder may be useful clinically, stringent criteria of the type listed in Table 1.1 are required for research purposes in order to allow comparisons across research studies.

Table 1.1

Diagnostic Criteria for SLI

Factor	Criterion
Language ability	Language test scores of –1.25 SD or lower
Nonverbal IQ	Performance IQ of 85 or higher
Hearing	Pass screening at conventional levels
Oral structure/function	Articulation test scores 85 or higher; no structural or functional anomalies
Social interactions	No symptoms of impaired reciprocal social interaction
Alternate diagnosis	No diagnosis of Autism Spectrum Disorder, or other pathology that may account for the language delay

Of course, one of the crucial criteria for SLI is the presence of significant limitations in language skills. Typically, the difficulties experienced by children with SLI span a wide range of language abilities with marked variability in individual profiles. A comprehensive assessment includes standardized tests of several aspects of language such as grammar and lexical knowledge allowing for the comparison of a child's current language level with the level expected for a child of that age. The criterion for a language deficit of a composite standardized score of 81 or lower has been adopted in many studies following an influential study by Records and Tomblin (1994) indicating that Speech-Language Pathologists agreed on the diagnosis of SLI for individuals scoring at least 1.25 standard deviations below the mean on composite language measures. Composite measures provide a robust estimate of performance because they are based on multiple measures of a construct, although their use is limited to composites of subtests from the same standardized test (Plante, 1998).

One of the most fundamental diagnostic criteria for SLI is the presence of a discrepancy between poor language functioning and age-appropriate nonverbal abilities, although there is growing dissatisfaction with this convention. Consistent with the arguments reviewed above concerning the category of SLI, some researchers have pointed out that the use of this discrepancy criterion is arbitrary, lacking in any strong justification (Plante, 1998), and subject to measurement error (Bishop, 1997b). In a recent twin study of the relationship between language impairment and poor nonverbal ability, Viding, Price, Spinath, Bishop, Dale, and Plomin (2003) reported that genes associated with language impairment are associated with nonverbal ability as well. Viding et al. argued that these findings point to a general genetic factor that includes both language and nonverbal problems, and suggested further that the requirement for a verbal-nonverbal discrepancy in SLI is artificial. There are other findings also implying that the verbal-nonverbal discrepancy criteria for SLI may be too simplistic: Even in studies where all participants score in the average range on nonverbal measures, SLI groups are often observed to have weaker nonverbal skills than same-age peers (cf. Leonard, 1998), and significantly poorer performance may be found (e.g., Eisenwort, Willinger, Schattauer, & Willnauer, 1999). Willinger and Eisenwort (1999) examined patterns of standardized intelligence test scores using cluster analysis for a group of 93 children who met the ICD-10 criteria for SLI. Two thirds of the group were found to have additional cognitive problems prompting these researchers to suggest that a basic cognitive deficit may underlie the disorder in at least some children with SLI. One additional puzzling finding is that whereas IQ measures tend to remain stable over time in typically developing children, the nonverbal IQ scores of children with SLI have been found to decline over time (Leonard, 1998), by more than 20 points between the ages of 7 and 11 in one study (Botting, 2005). It is clear from these studies that further exploration of this issue is warranted.

The studies encompassed in this thesis employed selection criteria consistent with those listed in Table 1.1. Two additional requirements were included: One was the requirement that the children with SLI have measurable deficits in both receptive and expressive language. This issue is discussed in section 1.1.3 below. The second was that the primary language of participants should be English in order to ensure that language differences could not be attributed to unfamiliarity with the English test materials or instructions.

1.1.2: Characteristics of SLI

Children with SLI have been found to have difficulty with virtually every aspect of language that has been studied. Impairments on nonlinguistic tasks have been reported also. While a complete review of the literature describing the characteristics of SLI is beyond the scope of this thesis, pertinent information will be described in some detail.

1.1.2.1 Lexical abilities. Although children with SLI are delayed in the onset of first words (Trauner, Wulfeck, Tallal, and Hesselink, 1995) and generally perform below age-level on a variety of lexical measures, lexical abilities appear to be an area of relative strength in SLI. When compared to children with matched lexical sizes and utterance lengths, children with SLI have been found to use similar word types (Leonard, Camarata, Rowan, & Chapman, 1982), learn new words at similar rates (e.g., Schwartz, 1988; Schwartz, Leonard, Messick, & Chapman, 1987), and have similar lexical diversity in spontaneous speech (e.g., Goffman & Leonard, 2000; Klee, Stokes, Wong, Fletcher, & Gavin, 2004; Owen & Leonard, 2002; Thordardottir & Ellis Weismer, 2001).

Nevertheless, there have been reports of particular weaknesses in the lexical abilities of children with SLI. Children with SLI learn fewer phonological and semantic features of briefly introduced novel words (Alt, Plante, & Creusere, 2004; Gray, 2004; Nash & Donaldson, 2005), require more exposures to learn to produce novel words (Dollaghan, 1987; Gray, 2003; Rice, Buhr, & Nehmeth, 1990; Rice, Buhr, & Oetting, 1992), have difficulty retaining newly learned words over time (Oetting, 1999; Rice, Oetting, Marquis, Bode, & Pae, 1994; Riches, Tomasello, & Conti-Ramsden, 2005), and use a more limited variety of verbs than children with similar language abilities (Conti-Ramsden &

Jones, 1997; Hadley, 1998; Watkins, Rice, & Moltz, 1993; Rice and Bode, 1993). Verb learning appears to present a marked challenge for children with SLI with disproportionate difficulty acquiring verb but not noun forms persisting well into the school years (Oetting, Rice, & Swank, 1995; Rice et al., 1994; Windfuhr, Faragher, & Conti-Ramsden, 2002).

One final aspect of lexical limitations commonly identified in SLI is 'word-finding' problems; the difficulty recalling desired words rapidly. Indications of a word-finding problem in spontaneous speech include hesitations, long pauses, use of non-specific language such as 'thing' or 'stuff', or use of related words such as 'chair' for 'table'. Slower response times for SLI groups have been found in free recall tasks (e.g., Kail & Leonard, 1986; Wekerly, Wulfeck, & Reilly, 2001), and in picture naming tasks at least for children with deficits in both receptive and expressive language (e.g., Kail & Leonard, 1986; Katz, Curtiss, & Tallal, 1992; Lahey & Edwards, 1996; Wiig, Semel, & Nystrom, 1982). One suggestion has been that poorer semantic representations in the lexicon contribute to this word retrieval failure (McGregor, Newman, Reilly, & Capone, 2002).

1.1.2.2 Grammatical abilities. As used here, grammar refers to the system of implicit rules in a language and encompasses syntax, grammatical morphology - bound morphemes such as verb inflections (e.g., jump*ed* or jump*ing*), and function words such as articles and auxiliary verbs. Difficulty with the acquisition of these implicit rules is probably the core deficit distinguishing SLI, and problems with grammatical morphology has become one of the hallmarks of SLI. Children with SLI produce fewer grammatical morphemes with a lower degree of consistency than typically developing children of the same age, despite the use of similarly complex syntactic constructions (e.g., Leonard, 1989; Schmauch, Panagos, & Klich, 1978; Steckol, & Leonard, 1979). Particular problems with verb-related morphology persisting well into school years and beyond are well-documented (e.g., Gopnik & Crago, 1991; King, Schelletter, Sinka, Fletcher, & Ingham, 1995; Leonard, Miller & Gerber, 1999) with reports of impairments in the marking of finite verbs for both agreement (e.g., Leonard, Miller, & Owen, 2000) and tense (Conti-Ramsden & Windfhur, 2002; Leonard, Deevy, Miller, Charest, Kurtz, & Rauf, 2003; Marchman, Wulfeck, & Ellis Weismer, 1999; Redmond, 2003; Rice, Wexler, & Cleave, 1995; Rice, Wexler, & Hershberger, 1998; van der Lely & Ullman, 1996). While much of the work on verb-related morphology in SLI has focused on English-speaking groups, error patterns for SLI groups whose primary languages are other than English generally have confirmed the vulnerability of grammatical morphology with particular patterns related to the typology of the respective languages (e.g., Bedore & Leonard, 2005; Hansson & Leonard, 2003; Hansson, Nettelbladt, & Leonard, 2000; Leonard & Bortolini, 1998; Leonard, Salameh, & Hansson, 2001).

Tense marking has been studied intensively in English speaking children with SLI. Verb morphology related to tense has been found to be particularly effective in distinguishing children with SLI and control children (Fletcher & Peters, 1984; Gavin, Klee, & Membrino, 1993). In a landmark study, Rice et al. (1995) found that children with SLI showed no change over a one year period in the level of use of the regular past and third-singular inflections, copula and auxiliary forms of *be*, and auxiliary *do*. The difficulties with tense extend to the receptive as well as expressive domains even for children whose difficulties appear to be limited to the expressive domain (van der Lely & Harris, 1990), and are disproportionate to deficits in other language skills such as utterance length and receptive vocabulary (Rice, 2003). The limitations appear to affect the rule-based regular past tense to a greater degree than the rote-learned irregular past tense (Rice, Wexler, Marquis, & Hershberger, 2000) and the past participle (Redmond, 2003; Leonard et al., 2003). Both tense marking (Rice, 2003; Rice & Wexler, 1996) and a broader measure of finite verb morphology (Bedore & Leonard, 1998; Leonard, et al., 1999) have been suggested as clinical markers of SLI.

While syntactic skills have been the focus of fewer studies, it is no surprise that complex sentence forms are challenging. Children with SLI have been found to produce fewer complex sentences (Marinellie, 2004; Schuele & Tolbert, 2001), omit markers in relative clauses (Schuele & Nicholls, 2000; Schuele & Tolbert, 2001), and have more difficulty comprehending and producing passives, reflexives and *Wh*-questions (van der Lely, 1998; van der Lely & Battell, 2003; van der Lely & Stollwerck, 1996). van der Lely (1998) has suggested that deficits on these tasks reflect a general impairment in the syntactic computations underlying hierarchical, structurally-complex forms.

1.1.2.3 Discourse. Extended speaking contexts can be highly demanding situations that present a particular challenge for individuals with SLI. In addition to the linguistic demands for well-constructed sentences, conversational interaction is associated with cognitive demands for organization, planning, and sequencing, as well as psychosocial demands for presupposing the partner's knowledge and language level, and approaching and interacting with a partner. Much of the research in this area has focused on narrative discourse. Story retelling has been found to be the best predictor of overall prognosis in both preschool and school age children with SLI (Bishop & Edmundson, 1987; Botting, Faragher, Simkin, Knox, & Conti-Ramsden, 2001). Children with SLI typically know the intent of the story and include the essential ingredients in an appropriate sequence, but have difficulty with the global organization of content and the use of linguistic structure (e.g., Fey, Catts, Proctor-Williams, Tomblin, & Zhang, 2004; Kaderavek & Sulzby, 2000; Liles, Duffy, Merritt, & Purcell, 1995; Miranda, McCabe, & Bliss, 1998; Thomson, 2005; Thordardottir & Ellis Weismer, 2002). Difficulties in conversation arise also because of the tendency of children with SLI to use ambiguous utterances and underspecified pronouns, or semantically inappropriate or inaccurate information (Yont, Hewitt, & Miccio, 2002).

1.1.2.4 Pragmatics. Generally, the language content, range of topics, and language use in context of children with SLI are broadly within normal limits relative to language level (e.g., Boudreau & Hedberg, 1999; Leonard, 1986; Mackie & Dockrell, 2004; Norbury & Bishop, 2003; Sturn & Johnston, 1999; van Kleek & Frankel, 1981), although some studies have noted reduced frequency of initiations and more restricted responses in conversation (e.g., Brinton, Fujiki, & Higbee, 1998; Brinton, Fujiki, & McKee, 1998; Johnston, Miller, Curtiss, & Tallal, 1993; Sturn & Johnston, 1999). There are indications, however, that differences exist in the social skills of children with SLI: Teacher and parent ratings suggest that children with SLI have higher levels of social reticence and behaviour problems, and lower levels of social competence and emotion regulation than typically developing children (e.g., Conti-Ramsden &

Botting, 2004; Fujiki, Brinton, & Clarke, 2002; Hart, Fujiki, Brinton, & Hart, 2004; Marton, Abramoff, Rosenzweig, 2005; McCabe, 2005).

One suggestion has been that the impaired social skills in SLI are not a characteristic of the disorder but a consequence arising as a result of poor social adaptation (Redmond & Rice, 1998). It is well known that living with a disability can negatively affect both self-perception and the perceptions of others, and this may account for some of the poor social skills evident in children with SLI. Findings from a study by Jerome, Fujiki, Brinton, and James (2002) provided support for this notion: Older but not younger children with SLI were found to rate themselves more poorly on a self-esteem measure than typically developing age-matched peers suggesting that the poorer self-ratings of the older group may be a consequence of living with the impairment for a longer period of time. Similarly, lower teacher ratings of social competence have been reported for children with SLI attending a special school but not a language unit (Farmer, 2000) raising the possibility that the poor social competence of the children in the special school arose as a consequence of their distorted social experiences, although a primary deficit in social cognition cannot be ruled out. The poor self-perception in SLI may not persist, however, as adults with a history of SLI generally report the same positive attitude about their lives despite completing fewer years of education and receiving lower rates of pay, than adult control respondents (Records, Tomblin, & Freese, 1992).

1.1.2.5 Speech sound system. Phonology refers to the sound system of a language. The term SLI does not encompass primary phonological disorders, although many children with SLI also have phonological impairments. Nevertheless, subtle phonological limitations have been reported for SLI groups without overt signs of phonological impairments. Children with SLI have been found to show delayed acquisition of sound segments, and syllable and word structures, and make more phonological errors than typically developing children (Aguilar-Mediavilla, Sanz-Torrent, Serra-Raventos, 2002; Owen, Dromi, & Leonard, 2001; Pharr, Ratner, Rescorla, 2000). The observed error patterns typically involve simplification processes including cluster reduction, weak syllable deletion, and final sound deletion (Bortolini & Leonard, 2000; Orsolini, Sechi, Maronato, Bonvino, & Corcelli, 2001). In addition to the phonological system, differences in motoric aspects of speech production have been reported also. Children with SLI have been found to have more difficulty producing well-organized and stable rhythmic speech motor movements than typically developing children of the same age (Goffman, 1999, 2004).

1.1.2.6 Nonverbal abilities. There is growing evidence that the impairments in SLI are not limited to the linguistic domain. Several studies have investigated higher order cognitive processes in SLI such as hypothesis testing and problem solving (e.g., Ellis Weismer, 1991; Nelson, Kamhi, & Apel, 1987), reasoning (e.g., Nippold, Erskine, & Freed, 1988), and symbolic representation (e.g., Kamhi, 1981; Johnston & Ramstad, 1983; Montgomery, 1993). In general, findings typically indicate some disadvantage for the children with SLI, however some studies have not found these deficits (e.g., Connell & Stone, 1994; Kamhi, Catts, Koenig, & Lewis, 1984; Kamhi, Ward, & Mills, 1995; Kiernan, Snow, Swisher, & Vance, 1997). More consistent findings have been reported in studies involving imagery including mental rotation (e.g., Johnston & Ellis Weismer, 1983; Swisher, Plante, & Lowell, 1994), haptic recognition (Johnston & Ramstad, 1983; Kamhi, 1981; Kamhi, et al., 1984), and recognition of facial or vocal affect (Dimitrovosky, Spector, Levy-Shiff, & Vakil, 1998; Trauner, Ballantyne, Chase, & Tallal, 1993).

In addition, children with SLI have been found to exhibit slower response times on a variety of tasks spanning both linguistic and nonlinguistic domains (e.g., Johnston & Ellis Weismer, 1983; Schul, Stiles, Wulfeck, & Townsend, 2004; Sinninger, Klatzky, & Kirchner, 1989; Miller, Kail, Leonard, & Tomblin, 2001). Substantial co-morbidity of motor incoordination (Hill, 2001; Johnston, Stark, Mellits, & Tallal, 1981) and limitations in attention (e.g., Niemi, Gundersen, Leppasaari, & Hugdahl, 2003) have also been reported.

1.1.2.7 Academic impact. There are at least two reasons why children with a language impairment may go on to have learning difficulties in other areas: (1) the deficits that contributed to the difficulties acquiring language may also impair learning in other areas, and (2) the presence of poor language skills place the child at a disadvantage for subsequent learning that is dependent on language. Academic difficulties in SLI are well documented for all domains including preliteracy skills (e.g., Boudreau & Hedberg, 1999; Joffe, 1998; Kaderavek & Sulzby, 2000), reading (e.g., Catts, Fey, Tomblin, & Zhang, 2002; Flax et al., 2003; Snowling et al., 2000), writing (e.g., Bishop & Clarkson, 2003; Fey et al., 2004; Mackie & Dockrell, 2004), and mathematics (e.g., Arvedson, 2002; Donlan & Gourlay, 1999; Fazio, 1999). One issue of considerable debate at the present time is whether children with language impairment and those with reading impairments represent one disorder group, or two (e.g., Bishop, 2001; Bishop & Snowling, 2004; Catts, Adlof, Hogan, & Ellis Weismer, 2005; Goulandris, Snowling, & Walker, 2000; Leonard, Lombardino, Walsh, Eckert, Mockler, et al., 2002; McArthur, Hogben, Edwards, Heath, & Mengler, 2000;

Nation, Clarke, Marshall, & Durand, 2004). One suggestion has been that reading comprehension impairments are associated with weak oral language skills and may overlap with SLI, whereas limitations confined to phonological processing skills are associated with poor reading mechanics such as decoding and spelling and represent a specific reading impairment distinguishable from SLI (e.g., Catts et al., 2005; Nation et al., 2004; Nation & Norbury, 2005; Snowling et al., 2000).

1.1.3: Subgroups

It may be misleading to present one term, SLI, as if it represents one unified disorder. The heterogeneous nature of SLI is the one thing about which there is wide spread agreement! Considerable efforts have been made to understand this heterogeneity by identifying subgroups within SLI, however a general consensus has yet to be reached. A number of studies have employed statistical procedures such as factor analysis (e.g., Aram & Nation, 1975; Conti-Ramsden, Crutchley, & Botting, 1997; Tomblin & Zhang, 1999; Wolfus, Moscovitch, & Kinsbourne, 1980), while others have been based on clinical judgements (e.g., Bishop & Rosenbloom, 1987; Rapin & Allen, 1983, 1987; Wilson & Risucci, 1986). One common finding is the broad distinction between individuals with SLI whose difficulties predominantly affect expressive skills, and those with a flatter profile with deficits in both expressive and receptive skills (e.g., Evans, 1996). Although the usefulness of this distinction has been questioned on several grounds (Bishop, 1997b), expressive-only impairments are associated with better overall prognosis and more favourable response to intervention. For research purposes, many researchers include only children with language deficits in both receptive and expressive language in their SLI groups in order to ensure that participants have a genuine, persistent, and marked difficulty learning language (e.g., Stark & Tallal, 1988; Rice & Oetting, 1993). This approach was adopted in the studies in this thesis.

Two specific SLI subgroups have been investigated and reported on in more detail. van der Lely and colleagues (van der Lely, 1994, 1996; van der Lely & Stollwerck, 1997) have described 'Grammatical SLI' (G-SLI), which is characterised by an impairment in the computations underlying hierarchical, structurally-complex forms in one or more components of grammar. This Representational Deficit for Dependent Relationships (RDDR) results in a pervasive deficit in grammatical components determined by structural complexity and affecting both comprehension and production. A second well-defined subtype is Semantic-Pragmatic Disorder, first described by Rapin and Allen (1983) and subsequently investigated in more detail by Bishop and colleagues (Bishop, 1997c, 2000; Bishop & Adams, 1989; Bishop, Chan, Adams, Hartley, & Weir, 2000; Bishop, Hartley, & Weir, 1994). The primary pragmatic difficulty is reflected in the child's use of syntactically well-formed, complex sentences, which do not appear to fit in with the context.

1.1.4: Theoretical perspectives

There is considerable interest in identifying the potential cognitive mechanisms that may underlie SLI. Such an understanding would provide clues about how language is learned generally, and may contribute to the development of effective intervention strategies for SLI. Several of the prominent theoretical perspectives are reviewed and considered throughout this thesis, but it is the contribution of potential impairments in immediate memory systems that form the basis of the present work. The following section describes, in detail, current theories regarding immediate memory, the links between immediate memory and language, and immediate memory function in children with SLI. Alternative accounts of SLI are considered in section 1.5 of this chapter.

1.2: Short-term and Working Memory

Immediate memory systems broadly encompass short-term memory and working memory. In simple terms, short-term memory refers to the retention of information for brief periods of time, while working memory refers to the simultaneous storage and processing of information. Short-term memory is often viewed as a subcomponent of working memory that is related to, but distinguishable from, working memory (e.g., Baddeley, 1986; Engle, Kane, & Tuholski, 1999). Several studies have provided support for the notion that short-term and working memory are separable constructs. For example, performances on tasks tapping short-term memory (storage-only) and working memory (storage plus processing) have been found to form separable factors in factor analyses (e.g., Cantor, Engle, & Hamilton, 1991; Engle, Tuholski, Laughlin, & Conway, 1999; Kail & Hall, 2001; Kane, Hambrick, Tuholski, Wilhelm, Payne, & Engle, 2004). Converging evidence comes from studies indicating that working memory but not short-term memory is related to measures of learning and scholastic attainment during childhood (e.g., Daneman & Carpenter, 1980; Gathercole, Pickering, Knight, & Stegmann, 2004; Kail & Hall, 2001; Swanson, 1992), and fluid intelligence in adults (e.g., Engle, Kane, et al., 1999). This section will describe short-term and working memory in detail.

1.2.1: Short-term memory

Short-term memory refers to a limited capacity system for the brief retention of information. The distinction between a limited-capacity primary memory (short-term memory) and an unlimited capacity secondary memory (long-term memory) was described as early as 1890 (James, 1890). There is now a great deal of evidence supporting a distinction between short-term and long-term memory. Many of the studies demonstrating the limited capacity of short-term memory were based on what has become classic research methodology in cognitive psychology. In the Brown-Peterson paradigm (Brown, 1958; Peterson & Peterson, 1959), participants are presented with a short list of three items followed by a retention interval during which they complete a distracting task such as counting backwards, and then attempt to recall the list. In its original version, the materials in the presentation (letters) and distraction tasks (numbers) were chosen based on long-term learning studies indicating minimal interference between them (McGeoch & McDonald, 1931). The extremely rapid forgetting occurring in this context, then, was attributed to short-term trace decay rather than interference effects from a long-term store.

Another standard paradigm, serial recall, requires immediate repetition of a presented list in correct serial order. Results from such tasks form a classic ‘serial position curve’ where recall starts very accurately, decreases throughout the list, and then improves towards the end of the list. One traditional interpretion is that this pattern is indicative of both short-term and long-term memory systems (Glanzer & Cunitz, 1966). According to this view, the recency effects reflect a short-term store in which the most recently presented items remain at the time of recall, and the primacy effects, the preservation of items that had sufficient time to activate associated semantic knowledge in long-term memory. It should be noted that some alternative accounts suggest that this pattern can be accommodated by a unitary view of memory (Nairne, 1992; Neath, 1998; Ranganath & Blumenfield, 2005). Serial recall will be considered in further detail in chapter 6 of this thesis.

The ability to retain information briefly in short-term memory appears to vary depending on the type of information involved. Two types of information have been studied in more detail, the immediate recall of verbal or phonological information (hereafter, verbal short-term memory) and visuospatial information (visuospatial short-term memory). Most relevant to the current work, findings from studies of children's verbal and visuospatial memory skills indicate that the retention abilities in each domain are largely unrelated (e.g., Pickering, Gathercole, & Peaker, 1998; Michas & Henry, 1994), and develop at different rates (e.g., Hitch, 1990). Claims of domain-specificity in short-term memory are further supported by findings of selective interference of concurrent visuospatial and verbal activities on the performance of same-modality tasks (e.g., Baddeley, Grant, Wight, & Thomson, 1975; Baddeley & Lieberman, 1980; Brandimonte, Hitch, & Bishop, 1992; Logie, 1986), of impairment of verbal or visuospatial short-term memory in neurologically impaired patients (e.g., Vallar & Baddeley, 1984), and by neuroimaging data indicating different localized brain activity for verbal and spatial short-term memory tasks (see Fletcher & Henson, 2001 for a review). Future research may identify further breakdowns in the domain-specificity of short-term memory such as memory for olfactory perception (e.g., White & Treisman, 1997), and kinaesthesia (e.g., Jordan, 1978).

1.2.1.1 Verbal short-term memory. The most detailed account of verbal short-term memory is provided by the phonological loop, a subsystem of the working memory model proposed by Baddeley and Hitch (1974). The phonological loop is assumed to consist of a phonological short-term store subject to rapid decay, and a subvocal rehearsal mechanism that can be used to maintain phonological representations within the store (Baddeley, 1986). Auditory linguistic inputs have obligatory access to the phonological store, and other inputs may be recoded as verbal information. This simple model has proved capable of accommodating a great deal of experimental evidence from normal adult participants, children, and neuropsychological patients (see Baddeley, 1997, and Gathercole & Baddeley, 1993, for reviews).

Several findings have now become hallmarks of verbal short-term memory. The presence of a phonological similarity effect, the impaired recall for items that share similar phonological structure, is typically attributed to the confounding effects of decay of phonologically similar representations in the short-term store (e.g., Baddeley, 1966; Conrad & Hull, 1964). Listening to irrelevant speech (e.g., Colle & Welsh, 1976; Salamè & Baddeley, 1982), but not pulsed noise (Salamè & Baddeley, 1987), during serial recall tasks results in poorer retention suggesting that the irrelevant speech effect is due to the obligatory access of phonological (but not other auditory) information to the short-term store. Temporal decay of the phonological representations in the short-term store is indicated by the word-length effect, the decreased recall accuracy for memory sequences with lengthy articulatory durations (e.g., Baddeley, Thomson, & Buchanan, 1975; Cowan, Saults, Winterowd, & Sherk, 1991).

Evidence for the importance of rehearsal processes is reflected in findings from a number of studies. For example, recall is reduced when rehearsal is prevented such as when individuals engage in articulatory suppression, the concurrent repetition of irrelevant sounds such as *the-the-the* (e.g., Baddeley, Lewis, & Vallar, 1984). Important developmental work suggests that the ability to rehearse items appears to emerge after about seven years of age (Cowan & Kail, 1996; Gathercole & Adams, 1993; Gathercole, Adams, & Hitch, 1994). Recently, a third component responsible for controlling timing mechanisms has been proposed to account for data pertaining to temporal grouping (e.g., Frankish, 1985, 1989; Hitch, Burgess, Towse, & Culpin, 1996) and the immediate recall of rhythmic tapping (e.g., Larson & Baddeley, 2003; Saito, 2001). Neuroimaging studies of short-term memory have identified distinguishable regions supporting each of these functions including recoding, storage, maintenance of temporal order, and rehearsal processes (e.g., D’Esposito, Postle, Ballard, & Lease, 1999; Henson, Burgess, & Frith, 2000).

It is clear that verbal short-term memory does not operate in isolation, but within the context of a complex cognitive system. Several studies have investigated the potential impact of other cognitive processes on verbal short-term memory. The support available from the knowledge base within long-term memory has been one such candidate process, and several lines of research point to the contribution of long-term knowledge to short-term memory performance. Examples include the better recall of familiar (known) words than nonsense syllables, known as the lexicality effect (e.g., Hulme, Maughan, & Brown, 1991), and the better retention of words in sentences than unrelated words (e.g., Baddeley, Vallar, & Wilson, 1987). Other phenomena considered to reflect the contribution of long-term knowledge include better recall for the following: (1) sound sequences with a higher probability of occurring in the lexicon, known as the phonotactic frequency effect (e.g., Gathercole, Frankish, Pickering, & Peaker, 1999; Munson, 2001); (2) words that are more frequently used, the word frequency effect (e.g., Hulme, Roodenrys, Schweickert, Brown, Martin, & Stuart, 1997); (3) words for which it is easier to form a mental image, the imageability effect (e.g., Bourassa & Besner, 1994); and (4) nonwords high in 'wordlikeness' (more similar to known words), the wordlikeness effect (e.g., Gathercole, 1995; Gathercole, Willis, Emsilie, & Baddeley, 1991). One account of the role played by long-term knowledge is that of redintegration, the use of activated lexical representations to reconstruct incomplete representations held in short-term memory (Gathercole, et al., 1999; Gathercole, Pickering, Hall, & Peaker, 2001; Hulme et al., 1997; Schweikert, 1993; Thorn, Gathercole, & Frankish, 2005). It has been suggested also that long-term knowledge may enhance the stability and quality of phonological representations themselves (Thorn & Frankish, 2005; Thorn et al., 2005).

Articulation rate is another mechanism found to be associated with verbal short-term memory (e.g., Cowan, Wood, Wood, Keller, Nugent, & Keller, 1998; Hulme & Tordoff, 1989) with developmental changes in articulation rate closely tied to changes in short-term memory (e.g., Henry, 1994; Hulme, Thomson, Muir, & Lawrence, 1984). Several researchers have reported superior recall for short- than long-duration words of matched syllable length (e.g., Baddeley et al., 1975; Hulme & Tordoff, 1989). It has been suggested that articulation rate may limit rehearsal in short-term memory, which is assumed to be a real-time process similar to covert speech (Landauer, 1962). Articulation rate, and speech skills more generally, may limit recall success at output as well (e.g., Vance, Stackhouse, & Wells, 2005; Wells, 1995). In contrast, Ferguson, Bowey, and Tilley (2002) have suggested that previous reports of the close association between articulation rate and memory span may be overestimated. These researchers argue that the common use of speech rate measures based on multiple word repetition may have introduced confounding effects because these measures themselves impose a memory load. Contrary to previous findings, Ferguson et al. reported that single-word speech rate accounted for only a small proportion of the variance in memory span performance in a group of primary school children.

1.2.1.2 Visuospatial short-term memory. The most detailed account of visuospatial short-term memory is provided by the visuospatial sketchpad, an additional subsystem of the working memory model proposed by Baddeley and Hitch (1974) analogous to the phonological loop (Baddeley, 1986; Logie, 1989, 1991; Morris, 1987). In more recent conceptualisations, specialized subcomponents for the retention of visual patterns (the visual cache) and sequences of movements (the inner scribe) have been suggested (Logie, 1995). This breakdown was based on an accumulation of evidence indicating dissociations between memory for spatial movements and for visual patterns including disruptive effects of concurrent movements on retention of spatial patterns (e.g., Baddeley & Lieberman, 1980; Klauer & Zhao, 2004; Logie, Zucco, & Baddeley, 1990; Smyth & Pendleton, 1989) and concurrent or interpolated viewing of irrelevant, changing visual material on retention of visual information (e.g., Klauer & Zhao, 2004; Logie, 1986; Quinn & McConnell, 1996). Neuropsychological evidence indicating selective impairments (e.g., Hanley, Young, & Pearson, 1991; Luzzati, Vecchi, Agazzi, Cesa-Bianchi, & Vergani, 1998), and developmental studies indicating different rates of developments (Logie & Pearson, 1997) have also pointed to these subcomponents.

Nevertheless, visual and spatial information are often tightly linked and the distinction between them unclear (i.e., object shape involves retention of spatial arrangement and visual features). As well, spatial information can sometimes be encoded in the form of static visual patterns (Smyth & Pendleton, 1989; see also Pickering, Gathercole, Hall, & Lloyd, 2001). The studies in this thesis investigate visuospatial short-term memory in SLI by employing tasks requiring the retention of integrated visual and spatial information.

1.2.2: Working memory

Working memory is generally viewed as a limited capacity system responsible for the temporary storage and processing of information (e.g., Baddeley, 1986; Just & Carpenter, 1992). The underlying cognitive processes that support working memory performance remain open to debate. According to the working memory model advanced originally by Baddeley and Hitch (1974) and developed subsequently by Baddeley and colleagues (Baddeley, 1996, 2000; Baddeley & Logie, 1999), working memory reflects multiple resources associated with distinct capacity-limited sub-systems. This model incorporates the central executive, which is associated with attentional control, high-level processing activities, and the coordination of activities within working memory.

The other two components correspond to the concepts of verbal and visuospatial short-term memory reviewed above, and are described in the working memory model as modality-specific slave systems responsible for the storage of verbal (the phonological loop) and visuospatial material (the visuospatial sketchpad). The episodic buffer (Baddeley, 2000) is the final component, responsible for integrating representations both within subsystems of working memory and across the cognitive system more generally.

A contrasting perspective views working memory as an undifferentiated limited resource that is shared between processing and storage (Daneman & Carpenter, 1980; 1983; Just & Carpenter, 1992). By this account, individuals vary not in the total amount of resource available but in the resource demands imposed by processing, such that individuals with inefficient processing will require more resources and hence have a reduced capacity to store information (e.g., Just & Carpenter, 1992; King & Just, 1991) or *vice versa*. Still other theories propose that working memory consists of long-term memory representations activated by a limited attentional resource (e.g., Barrouillet, Bernadin, & Camos, 2004; Cowan, 1995, 2001; Engle, Kane, et al., 1999).

These models are considered in this thesis, but it is the multiple component working memory model subsuming short-term memory (Baddeley, 2000; Baddeley & Hitch, 1974) that forms the basis of the work. The following subsections describe the components specific to the multiple-resource model of working memory in more detail.

1.2.2.1 The central executive. The central executive is considered to be important for the processing or manipulation of information during cognitive tasks (Baddeley, 1996). In its initial conceptualisation (Baddeley, 1986;

Baddeley & Hitch, 1974), the central executive was likened to the Supervisory Attentional System (SAS) discussed by Norman and Shallice (1980), a limited capacity system responsible for the control of action and attention. In more recent work, the central executive has been linked with a variety of control processes including temporary activation of long-term memory (Baddeley, 1998), coordination of multiple tasks (e.g, Baddeley, Della Sala, Papagno, & Spinnler, 1997), shifting between tasks or retrieval strategies (Baddeley, 1996), and selective attention and inhibition (Baddeley, Emslie, Kolodny, & Duncan, 1998). It is unknown whether these functions are performed by separate cognitive subsystems that can be selectively impaired, or represent subsystems of a single executive controller (Baddeley, 1996).

The central executive is considered to be a domain-general resource. Supporting evidence comes from investigations involving factor analyses indicating that a domain-general factor contributes to working memory performance (Bayliss, Jarrold, Gunn, & Baddeley, 2003; Engle, Tuholski, et al., 1999; Kane, et al., 2004). Results of some studies, however, have led to the suggestion that processing resources within working memory may be fractionated into distinct verbal and visuospatial components (Friedman & Miyake, 2000; Handley, Capon, Copp, & Harper, 2002; Jarvis & Gathercole, 2003; Jurden, 1995; Morrell & Park, 1993; Shah & Miyake, 1996). One problem for these studies is that the tasks employed involve both storage and processing. It is possible, then, that the dissociation on these tasks arises due to the domain-specific storage, leaving open the possibility that the processing resource may be domain-general. Findings consistent with this notion were provided by Shah and Miyake (1996) indicating that domain of storage items, rather than processing items, more strongly influenced correlations between same-domain working memory and general ability measures. This issue is addressed in several areas in the present research and particularly in chapter 4 with the aim of exploring domain-specific deficits in both processing and storage in SLI.

Within the working memory model, the short-term stores (i.e., the phonological loop and the visuospatial sketchpad) are proposed as sub-systems, or slave systems, governed by the central executive. In the case of both verbal and visuospatial short-term memory, recent evidence suggests that this view may be too simplistic. Saeki and Saito (2004) recently demonstrated that verbal short-term memory plays an important role in task switching, an executive control function previously attributed to the central executive, at least when no external cue is provided. An even stronger tie with the central executive has been suggested for visuospatial short-term memory (e.g., Baddeley, Cocchini, Della Sala, Logie, & Spinnler, 1999; Miyake, Friedman, Rettinger, Shah, & Hegarty, 2001). Findings indicate that maintaining mental representations of visual stimuli can be effortful and place demands on the central executive (Baddeley et al., 1999). In addition, visuospatial short-term and working memory measures have been found to load on the same factor in factor analyses in some studies (Miyake et al., 2001).

1.2.2.2 The episodic buffer. The episodic buffer was proposed as an additional component of working memory (Baddeley, 2000) in order to account for an array of findings that could not be accommodated easily by the original three-component model (Baddeley & Hitch, 1974). For instance, there was strong evidence to suggest that long-term memory can play a role in supporting short-term and working memory (e.g., Chase & Ericsson, 1981), and that under some circumstances temporary storage of materials in quantities that exceed the capacities of the short-term stores can be achieved (e.g., Baddeley, et al., 1987). The episodic buffer was proposed as a limited capacity system capable of binding information from both working and long-term memory in a unitary episodic representation. One key suggestion was that the buffer stores information in a multimodal code making it capable of integrating information from various resources.

1.2.3: Measures of short-term and working memory

Short-term and working memory both involve temporary storage, but are distinguished by whether or not significant processing activity is required concurrently. The tasks assumed to tap these resources differ along similar lines: short-term memory tasks impose storage but minimal processing demands, whereas working memory tasks engage the participant in significant processing activity in addition to storage. Short-term memory tasks typically involve the immediate recall of information, and may employ either serial or free recall, serial recognition, or recreation of a pattern. The most widely employed measures of working memory are complex memory span paradigms, in which participants engage in some form of processing activity such as reading sentences or performing mental rotation, and simultaneously maintain information for subsequent recall. Typically, these tasks are administered in a span procedure aimed at measuring capacity of the resource by increasing the sequence length of trials until recall errors are made. Verbal and visuospatial measures have been developed for both short-term and working memory in line with the research reviewed above indicating domain-specific resources in short-term memory (see section 1.2.1), and raising the possibility of domain-specific resources in working memory (see section 1.2.2).

Conventional measures of verbal short-term memory include serial recall of words, letters or digits (e.g., Conrad & Hull, 1964). It must be noted that long-term memory may play a role in such tasks (i.e., the word frequency effect and the imageability effect; see section 1.2.1.1 above). Nonword repetition is an additional measure in common use that requires the repetition of novel phonological forms such as /wʊgə'læmɪk/. It has been suggested that nonword repetition provides a relatively pure index of verbal short-term memory because of the reduced availability of long-term lexical knowledge to support the unfamiliar phonological forms (e.g., Gathercole & Baddeley, 1989, 1993). It has proved a simple and effective task with valid measurements reported for children as young as two years of age (Roy & Chiat, 2004). Even nonword recall, however, may tap long-term knowledge: nonword repetition performance has been found to be influenced by the wordlikeness effect (e.g., Gathercole et al., 1991; Nimmo & Roodenrys, 2002), the phonotactic frequency effect (e.g., Munson, 2001; see also section 1.2.1.1 above), and by the prosodic pattern of a nonword (e.g., Dollaghan, Biber, & Campbell, 1995; Roy & Chiat, 2004).

It should be noted that this interpretation of nonword repetition is not universally held. Alternative accounts suggest that nonword repetition taps other cognitive processes including lexical knowledge (Snowling, Chiat, & Hulme, 1991), phonological sensitivity (e.g., Bowey, 1996; Metsala, 1999; Reuterskiold-Wagner, Sahlen, & Nymen, 2005), and output phonology (e.g., Sahlen, Reuterskiold-Wagner, Nettelbladt, & Radeborg, 1999; Wells, 1995).

Understanding of the cognitive processes that support nonword repetition is an important issue in this thesis and will be explored in some detail, predominantly in chapters 5 and 6.

Visuospatial versions of short-term memory tasks involve the retention of either visual patterns or sequences of movements (e.g., Smyth & Scholey, 1996; Wilson, Scott & Power, 1987). One challenge in designing visuospatial tasks generally is that many individuals have a tendency to recode visuospatial information verbally (i.e., describing a shape to themselves with the verbal label ‘circle’), and once the information has been entered into verbal short-term memory the task is no longer a visuospatial measure. In this area, then, it is particularly important to make use of well-designed, validated measures, as was the case in this thesis.

Domain-specific complex memory measures have been developed to assess working memory as well. An example of a verbal complex memory task is reading span, in which the participant is asked to make a meaning-based judgment about each of a series of sentences and then remember the last word of each sentence in sequence (e.g., Daneman & Carpenter, 1980). A corresponding visuospatial task is spatial span, in which the participant is asked to judge the orientation of a set of letters, and then remember the sequence of degrees of rotation of the letters (Shah & Miyake, 1996). Within the working memory model, the storage demands of complex memory tasks are suggested to depend on appropriate short-term subsystems, with processing supported principally by the central executive (Baddeley & Logie, 1999; Cocchini, Logie, Della Sala, MacPherson, & Baddeley, 2002).

Several proposals exist concerning the cognitive processes that may be engaged in complex memory tasks. One account consistent with the working memory model (Baddeley & Hitch, 1974) is that of task-switching (Towse & Hitch, 1995), according to which individuals alternate between processing and storage aspects of the task. Increased processing demands have the effect of extending the time over which items may be forgotten. A more explicit view has been advanced by Barrouillet and Camos and colleagues (Barrouillet, Bernadin, & Camos, 2004; Barrouillet & Camos, 2001; Gavens & Barrouillet, 2004), who suggest that performance on complex span tasks is constrained by a limited attentional resource that is required to support both processing activities involving memory retrievals and item storage. Barrouillet et al. introduced the notion of cognitive load – the extent to which attention is switched away from maintenance to retrieval during a particular period – as the crucial determinant of complex memory span. Still another proposal comes from resource sharing accounts of working memory, according to which the limited capacity resource pool is employed for both processing and storage (e.g., Daneman & Carpenter, 1980; Just & Carpenter, 1992), and individual differences in task performance arise due to differences in processing speed.

1.3: Immediate Memory and Language

The apparent ease with which most individuals acquire and use their native language is a mini-miracle that has puzzled researchers for many years. Typical adults command a huge reserve of expert knowledge on the phonological structure and meaning of many thousands of lexical and sublexical units and the rules for combining them, as well as rules pertaining to their use and interpretation in different communication contexts. During everyday language use, there are constant demands for acquiring new word forms and meanings, formulating and understanding complex messages, and revising and reinterpreting messages. It has been suggested that complex cognitive activities such as these are supported by working memory (Baddeley & Hitch, 1974). The focus of the following section is to review research pertaining to the contribution of short-term and working memory to the acquisition and processing of language.

1.3.1: Verbal short-term memory and language

There is now an abundance of evidence linking verbal short-term memory to vocabulary knowledge and new word learning. Several studies have demonstrated close and specific associations between verbal short-term memory measures and vocabulary both for knowledge of the native language (e.g., Adams, Bourke, & Willis, 1999; Avons, Wragg, Cupples, & Lovegrave, 1998; Gathercole & Baddeley, 1989; Gathercole, Hitch, Service, & Martin, 1997; Gathercole, Willis, Emslie, & Baddeley, 1992; Michas & Henry, 1994), and foreign language acquisition (e.g., Dufva & Voeten, 1999; Masoura & Gathercole, 1999, 2005; Service, 1992; Service & Kohonen, 1995; Speciale, Ellis, & Bywater, 2004). Typically, the association is strongest during the early stages of language acquisition. For example, in a longitudinal study of vocabulary development in 4 to 8 year old children conducted by Gathercole et al. (1992), there was a marked decrease in the link between verbal short-term memory and vocabulary skills for the 8 as compared to 4 year olds. In foreign language learning as well, once individuals gain some facility with the foreign language, there is a diminished relationship with memory skills (Cheung, 1996; Masoura & Gathercole, 2005).

This pattern of findings has led to the suggestion that two resource pools support vocabulary development (Baddeley, Gathercole, & Papagno, 1998; Gathercole, in press; Gathercole et al., 1992). Verbal short-term memory plays an important role in the early stages of learning when there is little available support from existing lexical knowledge. In later stages, however, the amassed lexical store provides support for new word learning; novel phonological forms activate similar lexical and sublexical units within long-term memory thereby facilitating acquisition.

According to this view, then, verbal short-term memory is important in new word learning when lexical-mediation strategies are unavailable or ineffective. Phonological representations of brief and novel speech events are generated within short-term memory facilitating the creation of a phonological entry within the long-term lexical store. Consistent with this account, the link between verbal short-term memory and word learning has been found to be restricted to the learning of the phonological form, and not the semantic associations with the new word (Gathercole et al., 1997). In addition, verbal short-term memory is associated with new word learning even in adults when the novel forms are sufficiently unfamiliar as to render a lexical-mediation strategy ineffective (Atkins & Baddeley, 1998; Gupta, 2003).

Experimental studies of new word learning in specific populations have provided further support for the role of verbal short-term memory in vocabulary acquisition. Poor verbal short-term memory has been found in children with difficulties acquiring a foreign language (Palladino & Cornoldi, 2004), and to be associated with slower new word learning (Gathercole & Baddeley, 1990b; Gathercole et al., 1997). In an important study by Papagno and Vallar (1995) comparing young adults classified as either polyglots (proficient in a minimum of three languages) or non-polyglots, verbal short-term memory as indexed by nonword repetition was found to be better in the polyglots, as well as highly and specifically associated with the ability to learn novel words in an experimental task.

More broadly, poor verbal short-term memory characterizes groups of children with particularly marked impairments of language learning, including individuals with specific reading disabilities (e.g., Snowling, 1983; Swanson & Berninger, 1995), and Down's syndrome (e.g., Laws, 2004). Interestingly, verbal short-term memory skills have been found to be preserved in William's syndrome, a syndrome characterized by relatively strong language skills but impaired visuospatial processing (e.g., Majerus, Barisnikov, Vuillemin, Poncelet, & van der Linden, 2003).

Links between verbal short-term memory and other aspects of language have been investigated as well. Differences in the verbal short-term memory of young children have been found to be associated with variation in spoken narrative skills (Adams & Gathercole, 1996), utterance length and range of syntactic constructions used (Adams & Gathercole, 1995, 2000), and letter knowledge (de Jong & Olson, 2004). In addition, children with good verbal short-term memory have been found to repeat spoken sentences more accurately, but not to differ in sentence comprehension when compared to a group with relatively poor memory (Willis & Gathercole, 2001). On this basis, it was suggested that verbal short-term memory makes a more direct contribution to sentence repetition than to sentence comprehension (Willis & Gathercole, 2001; see also, Hanten & Martin, 2000). It may be that verbal short-term memory plays a role in comprehension, but only when the material is particularly complex or demanding (Baddeley, 1997; Gathercole & Baddeley, 1993).

Despite the demonstrated associations with vocabulary and other language skills, poor verbal short-term memory may be insufficient, on its own, to cause a lasting impairment in language. In a recent study, children with a history of very poor verbal short-term memory that extended between 4 and 8 years of age were found to have age-appropriate language abilities four years later (Gathercole, Tiffany, Briscoe, Thorn & ALSPAC, 2005). Similarly, neuropsychological patients with severe impairments of verbal short-term memory often retain near normal spontaneous language use (e.g., Shallace & Butterworth, 1977). It may be that language learning within natural contexts has sufficient redundancy, affording repeated exposures to lexical and other linguistic forms, so that in time, even children with poor verbal storage abilities achieve age-appropriate levels.

1.3.2: Visuospatial short-term memory and language

It would be logical to assume that visuospatial short-term memory would not play an important role in language abilities. The available evidence is largely consistent with this assumption. No association has been found between measures of visuospatial short-term memory and vocabulary or language comprehension (Adams et al., 1999). Also, no differences in visuospatial short-term memory skills were observed in the study described above comparing polyglot and non-polyglot groups (Papagno & Vallar, 1995), or in another study comparing average and less-skilled readers (Swanson & Berninger, 1995, see also Del Giudice, Trojano, Fragassi, Posteraro, Cristani, et al., 2000).

Nevertheless, it may be that visuospatial skills support language in some contexts. For example, the comprehension of spatial language terms (i.e., above, below) has been found to be problematic for children with William's syndrome (Phillips, Jarrold, Baddeley, Grant, & Karmiloff-Smith, 2004), and completing a concurrent visuospatial task has been found to disrupt comprehension of spatial but not nonspatial text (DeBeni, Pazzaglia, Gyselinck, & Meneghetti, 2005; Pazzaglia & Cornoldi, 1999). In addition, visual codes may be used to recall verbal items when subvocal rehearsal mechanisms in verbal short-term memory are unavailable (e.g., Hitch, Halliday, Schaafstal, & Schraagen, 1988; Duyck, Szmalec, Kemps, Vandierendonck, 2003; Papagno, Valentine, & Baddeley, 1991). For example, Hitch et al. (1988) compared 5 year old children whose ability to rehearse items in verbal short-term memory has not yet emerged and 11 year olds on list recall of pictures that were either visually similar (leading to confusions for visuospatial memory) or had long names (leading to capacity limitations for verbal memory). The older children were uninfluenced by visual similarity but had more difficulty recalling the longer names, whereas the younger children were poorer at recalling the visually similar than dissimilar sequences. This pattern of findings suggests a developmental shift from dependence on visuospatial short-term memory perhaps prior to the emergence of subvocal rehearsal towards the use of verbal coding in picture recall.

Written language is one area that may be expected to depend on visuospatial skills to some extent, although strictly speaking, the aspects of written language that may be related to visuospatial skills may fall outside of the language domain. For example, visuospatial abilities may be involved in orientation of text and characters, place keeping, and writing mechanics. Consistent with this, visuospatial short-term memory has been found to be related to the early stages of learning to write (Manso, & Ballesteros, 2003) and decode (Meyler, & Breznitz, 1998).

1.3.3: Working memory and language

Everyday language use places constant demands on the ability to simultaneously store and process information, for example, recalling what someone has said, remembering the message while deciding how to phrase it, replaying a friend's last sentence subvocally while trying to figure out who 'he' is, or remembering what is to be written down while trying to locate a pen. It is clear, then, that working memory may play an important role in language, as it is expected to in other complex cognitive activities (Baddeley, 1986).

Several studies involving individual differences analyses have born out this prediction. Strong positive links have been demonstrated between complex memory tasks (e.g., listening or reading span, see section 1.2.3) and a range of language measures including reading comprehension (e.g., Daneman & Carpenter, 1980, 1983; Oakhill, Yuill, & Parkin, 1986; Yuill, Oakhill, & Parkin, 1989; Siegel, 1994; Swanson, 1994), language comprehension (King & Just, 1991; MacDonald, Just & Carpenter, 1992), following directions (Engle, Carullo, & Collins, 1991), and vocabulary learning in context (Daneman &

Green, 1986). The relationship of working memory with language, however, is by no means unique. Working memory capacity reliably predicts performance of both children and adults on a wide variety of complex cognitive activities including reasoning (Kyllonen & Christal, 1990), complex learning (Kyllonen & Stephens, 1990; Shute, 1991), spelling (Kreiner, 1992), and mental arithmetic (e.g., Adams & Hitch, 1997; DeStefano & LeFevre, 2004). Strong relationships with general intelligence (Engle, Tuholski, et al., 1999) and scholastic achievement (Bayliss et al., 2003) have also been reported.

Working memory has consistently been shown to be a better predictor of learning abilities than short-term memory (e.g., Engle, Tuholski, et al., 1999; Gathercole & Pickering, 2000; Swanson, 1994). Working but not short-term memory impairments have been found to characterize children performing below expectations on the National Curriculum (Gathercole & Pickering, 2000), children with poor reading comprehension (Swanson & Beringer, 1995), and children with persistent learning difficulties (Gathercole, et al., 2005). Impairments of both short-term and working memory have been associated with severe learning difficulties (Gathercole & Pickering, 2001; Henry, 2001).

The influence of working memory on such a wide range of everyday activities and cognitive skills may be problematic for a research program seeking to identify the cognitive underpinnings of impairments disproportionately affecting the language domain. One possibility is that the domain-specific short-term stores operating within working memory can be differentially impaired with deficits in verbal short-term memory leading to impairments in the linguistic domain. As reviewed in section 1.3.1 above, however, poor verbal short-term memory function alone does not appear to result in lasting language deficits (Gathercole & Pickering, 2000; Gathercole et al., 2005). Another possibility, then, is that the processing resources within working memory function with some domain-specificity, and may be differentially impaired. While some studies have demonstrated specific associations between verbal complex memory and verbal abilities, and between spatial complex memory and spatial abilities (Shah & Miyake, 1996), others have found cross-domain effects (Daneman & Merikle, 1996). As a final mechanism, it may be that both domain-general processing and domain-specific storage resources are implicated in impairments that both disproportionately affect the language domain, and persist over time. These questions comprise one of the primary foci of this thesis, and are considered throughout it, particularly in chapters 2, 3, and 4.

1.4: Immediate Memory in Children with SLI

The preceding section established that immediate memory skills influence language learning. The accumulated evidence suggests that verbal short-term memory is specifically associated with learning the phonological forms of words, and that working memory is implicated in more complex language tasks such as learning the conceptual aspects of words (Daneman & Green, 1986), and following directions (Engle, et al., 1991). Visuospatial short-term memory appears to play a minimal role in language. If deficits in immediate memory processes underlie the language impairments of SLI, then children with SLI may be expected to have deficits in these areas. The following section reviews current evidence pertaining to the skills of children with SLI in verbal and visuospatial short-term memory, and working memory.

1.4.1: Verbal short-term memory in SLI

Much of the support for a verbal short-term memory deficit in SLI comes from studies of nonword repetition. Children with SLI have marked impairments in multi-syllabic nonword repetition (e.g., Briscoe, Bishop, & Norbury, 2001; Conti-Ramsden, 2003b; Dollaghan & Campbell, 1998; Edwards & Lahey, 1998; Ellis Weismer, Tomblin, Zhang, Buckwalter, Gaura Chynoweth, & Jones, 2000; Farmer, 2000; Gathercole & Baddeley, 1990a; Gray, 2003; Kamhi & Catts, 1986; Kamhi, Catts, Maurer, Apel, & Gentry, 1988; Montgomery, 2004; Marton & Schwartz, 2003; Norbury, Bishop, & Briscoe, 2002; Sahlen, et al., 1999; Stothard, et al., 1998). The nonword repetition deficit characterizes children with SLI of all ages, from preschool (Gray, 2003), through to adolescence (Conti-Ramsden, et al., 2001; Stothard, et al., 1998). Even children with a history of SLI whose oral language is no longer distinguishable from age peers continue to perform poorly on tests of nonword repetition (Bishop, et al., 1996; Conti-Ramsden, et al., 2001).

The magnitude of the nonword repetition deficit in SLI appears to be disproportionate to the language impairment. In Gathercole and Baddeley's (1990a) study, the children with SLI as a group had a mean chronological age of about eight years and an age-equivalence of about six years on standardized measures of language including vocabulary, comprehension, and reading. However, their nonword repetition performance was impaired in comparison with a younger group of typically developing children matched for language ability, with scores of the SLI group corresponding to those of the average four-year-old child, representing a four year lag in repetition ability (Gathercole &

Baddeley, 1993). The poor nonword repetition skills of children with SLI even relative to younger children matched for language abilities have been replicated in the few studies that have included this comparison (Edwards & Lahey, 1998; Montgomery, 1995a). Interestingly, in a recent study of 242 eleven-year-old children with SLI, only 6% scored above the 84th percentile on a nonword repetition test, and the language abilities of this group were significantly greater than poor scorers with matched nonverbal cognitive skills (Botting & Conti-Ramsden, 2001).

Not all of the evidence for a verbal short-term memory deficit in SLI comes from nonword repetition; some studies have employed more conventional measures. Although typically the magnitude of the deficit is not as great as compared to nonword repetition (e.g., Gathercole & Baddeley, 1990a; see also, Conti-Ramsden, 2003b), children with SLI have been found to perform more poorly than their typically developing peers on serial recall of digits and words (Graham, 1980; Hick, Botting, & Conti-Ramsden, 2005), and the free-recall of pictured or spoken items (Kail, Hale, Leonard, & Nippold, 1984; Kirchner & Klatzky, 1985). In one study, length and sentence repetition were found to be unrelated for typically developing children, but negatively correlated for children with SLI (Menyuk, 1964). Montgomery (1995b) examined verbal short-term memory load and sentence comprehension in children with SLI and younger children with matched language abilities. The groups were compared in a picture-pointing task for the comprehension of short, linguistically nonredundant (e.g., “The girl smiling is pushing the boy”), and long, linguistically redundant sentences (e.g., “The girl who is smiling is pushing the boy”). It was predicted that if short-term memory limitations contribute to the performance of the SLI group, they should have more difficulty comprehending the longer sentences. The results were consistent with this hypothesis. The SLI group comprehended fewer longer than shorter sentences relative to themselves and compared to the control group, whereas the control children comprehended a comparable number of both sentence types. Similar findings have been reported in other studies as well (Curtiss & Tallal, 1991; Tallal, 1975). Converging evidence comes from work by Fazio (1997) indicating that children with SLI have problems remembering lines of common nursery rhymes and often recalling rhymes in an unconventional order.

The abundant evidence reviewed above indicates that a verbal short-term memory deficit characterizes SLI, but that nonword repetition is considerably more sensitive to the impairment than other measures. The investigation and consideration of verbal short-term memory deficits in children with SLI is a central topic of this thesis. Conventional and standardized serial recall and nonword repetition measures are employed for this purpose (chapter 2 and 5). Experimental manipulations designed to explore the factors influencing nonword repetition are also instrumental (chapter 6).

1.4.2: Visuospatial short-term memory in SLI

Visuospatial short-term memory has received much less attention in SLI. The few studies that have investigated short-term memory for visuospatial information in SLI have yielded mixed results. Three older studies reported the reduced ability of children with ‘developmental dysphasia’ to recall the spatial position or sequence of a stimulus compared to children with normal language function, but only in the condition where a silent time delay was introduced between presentation of the stimulus and response (Doehring, 1960; Poppen, Stark, Eisenson, Forrest, & Wertherm, 1969; Wyke & Asso, 1979). Montgomery (1993) also found SLI deficits when durational demands for retaining a visual representation of an object in a haptic recognition task increased. For all of these studies, the impaired performance was observed only after a delay. The introduction of a delay is problematic because it may allow time for visuospatial information to be recoded verbally, which may place children with typical language skills in the control groups at an advantage.

Another problem with studies attempting to assess visuospatial short-term memory in SLI is that they typically have not employed conventional measures. For example, some studies have included tasks requiring the recognition of patterns (Bavin, Wilson, Maruff, & Sleeman, 2005), or the serial recall of locations indicated by changing or disappearing coloured objects (Bavin et al., 2005; Hoffman & Gillam, 2004). While visual codes may be used to store pattern and colour information (Logie, 1995), the verbal recoding of such stimuli cannot be ruled out (Garro, 1986; Palmer, 2000) raising the possibility that the poorer performance of the SLI groups in both of these studies (Bavin et al., 2005; Hoffman & Gillam, 2004) may be due to the advantage of the control groups in using verbal recoding.

It should be noted that equivocal results for SLI and age-matched groups have also been reported. Bavin et al. (2005) did not find differences when their SLI and control groups were compared on spatial recognition, a task requiring the forced-choice of a shape previously appearing in a series, and a paired-associate learning task requiring the indication of the location in which a specified shape had previously appeared. Hick et al. (2005) compared a group of 3-year-old children with SLI and typically developing children of the same age on a visuospatial short-term memory task involving remembering the location of sharks in the sea. The visuospatial short-term memory skills were similar for the two groups, although those of the SLI group showed slower development over time.

On balance, the available evidence regarding visuospatial short-term memory in SLI is inconclusive. In this thesis, conventional, standardized measures are employed to investigate visuospatial short-term memory systematically in a group of children with SLI (chapters 2 and 3).

1.4.3: Working memory in SLI

Substantial deficits in working memory have been reported for children with SLI. Typically, these studies have employed complex memory tasks requiring the simultaneous storage and processing of information (see section 1.2.3). Ellis Weismer, Evans, and Hesketh (1999) reported poorer word recall on a listening span task for a group of school-age children with SLI compared to typically developing children of the same age. Children with SLI have also been found to perform less well than typically developing groups on tasks requiring mental reordering of items prior to recall (Montgomery, 2000b), and identification of colours prior to recall (Hoffman & Gillam, 2004). Ellis Weismer, Plante, Jones, and Tomblin (2005) compared adolescents with and without SLI on a modified listening span measure involving sentence encoding and recognition of final words in an fMRI study. The SLI group performed more poorly on the task, displayed slower reaction times on each portion of the task, and exhibited significant hypoactivation during encoding in regions implicated in attention and memory and during recognition in regions associated with language processing. Lower scores on a reading span task have also been reported for college-enrolled adults with a history of receiving speech and language services when compared to adults without such history (Isaki & Plante, 1997).

One feature common to the complex memory tasks described above is that they require the maintenance and manipulation of verbal information and so indicate that individuals with SLI are impaired in their ability to simultaneously store and process even simple, highly familiar verbal information over brief periods of time. The temporary storage and processing of nonverbal information has been the focus of only a few studies. Bavin et al. (2005) included one measure of visuospatial storage and processing in their study, a spatial search task, which required children to search for a shape in different locations and remember their already-searched-locations in order to avoid accumulating errors by re-searching them. No significant differences between their SLI and age-matched groups were found. One study has reported SLI deficits in spatial recall when combined with a colour identification task (Hoffman & Gillam, 2004). As noted previously, however, the use of colour identification may introduce opportunities for verbal recoding making the Hoffman and Gillam task potentially a verbal processing plus spatial storage task.

Of course, it is possible to argue that the poor performance of SLI groups on the verbal complex memory tasks reported above is simply a consequence of their verbal short-term memory deficits. One study in particular demonstrated that the presence of concurrent processing further impairs performance in SLI:

Marton and Schwartz (2003) compared SLI and age-matched groups on tasks involving either nonword repetition in isolation, or processing a syntactically simple or complex sentence and repeating the sentence-final nonword. The findings clearly showed the cost of the additional processing. The SLI group while impaired in the isolated nonword repetition task as expected, showed further decrements relative to the control group in nonword repetition with each increase in syntactic complexity.

At present, then, the available evidence suggests that children with SLI do have working memory difficulties, but that these limitations disproportionately affect both the storage and processing of information in the verbal domain. While the framework presented above for short-term storage (section 1.2.1) can accommodate this domain-specificity, the issue for processing within working memory is still unclear. As indicated in section 1.2.2, the concept of a central executive component within working memory as a domain-general resource has been supported by results from several studies (e.g., Bayliss et al., 2003; Kane et al., 2004), but has also been challenged by other findings (e.g., Handley, et al., 2002; Shah & Miyake, 1996). The issue of domain-specificity in potential storage and processing deficits in SLI is addressed throughout this thesis, and specifically in chapters 2, 3, and 4. Findings of processing limitations that cross verbal and visuospatial domains would provide support for a domain-general processing resource, whereas a deficit restricted to the verbal domain would point to domain-specificity within working memory. The question of domain-specific processing impairments in SLI is also of importance in relation to other evidence pertaining to SLI. Investigations targeting information processing in SLI have not supported a domain-specific view, but have demonstrated limitations in both verbal and nonverbal activities (e.g., Miller et al., 2001; see also section 1.1.2.6 above), and any theoretical account of SLI must accommodate these findings.

1.5: Theoretical Perspectives of SLI

As noted earlier, there is considerable interest in identifying the potential cognitive mechanisms that may underlie SLI, both from the perspective of understanding language learning generally, and developing intervention for language impaired populations. In this section, brief summaries of several prominent theoretical perspectives are presented, beginning with those most pertinent to the present work but including contrasting perspectives as well. The accounts generally fall into two categories, those proposing impairments to underlying cognitive processes whether general or specific, and those emphasizing deficits of specialized linguistic mechanisms.

1.5.1: Impairments of verbal short-term memory

A detailed review of theory and evidence pertaining to verbal short-term memory in general, and in SLI specifically has been provided in previous sections (1.2.1.1; 1.3.1; 1.4.1) and will not be repeated here. Based on findings of marked impairments in their SLI group compared to younger, language-matched controls, Gathercole and Baddeley (1990) suggested that a verbal short-term memory deficit may play a causal role in SLI. In later work, Gathercole and colleagues (e.g., Baddeley, Gathercole, et al., 1998; Gathercole, in press) have provided evidence that verbal short-term memory is specifically implicated in the learning of the phonological forms of new words (see section 1.3.1). The deficit in verbal short-term memory that characterizes SLI (e.g., Kirchner & Klatzky, 1985; Montgomery, 1995a, b; see also section 1.4.1), then, is suggested as one factor that limits language learning in SLI, specifically restricting the learning of the phonological forms of the language.

1.5.2: Impairments of general processing speed or capacity

'General processing' as used here refers to the processing of information currently occupying attention, and corresponds in many respects to the domain-general processing resources of the central executive presented in sections 1.2 to 1.4 of this chapter. Two aspects of general processing have been considered in theoretical accounts of SLI, speed (Kail, 1994) and capacity (Bishop, 1992; Ellis Weismer, 1996). It should be noted that processing capacity and speed are closely linked. Reduced processing capacity may reflect a limitation in the available resource (i.e., smaller workspace), but may also arise due to inefficient processing (i.e., deficits in speed). Speed of processing is a measure of processing activities only, such as reaction time in mental rotation or picture matching tasks. As such, processing speed may be compared directly to accounts of the processing resources within a multi-component model of working memory as adopted in this thesis. Processing capacity, on the other hand, reflects the capacity to engage in processing under differing processing loads and storage requirements. Some studies use complex memory paradigms (requiring processing and storage) as a measure of processing capacity (e.g., Ellis Weismer, et al., 1999), whereas others employ tasks varying in processing load (e.g., varying presentation modality and need for inference; Ellis Wesimer, 1985; Johnston & Smith, 1989). This notion is more consistent with a resource-sharing perspective which views working memory as an undifferentiated limited resource that is shared between processing and storage (Daneman & Carpenter, 1980, 1983; Just & Carpenter, 1992; see section 1.2.2).

Consider first processing speed. Children with SLI perform a variety of linguistic and nonlinguistic tasks more slowly than their peers. Slower reaction times for SLI groups have been found for verbal tasks including picture naming (Kail & Leonard, 1986; Lahey & Edwards, 1996; Miller, et al., 2001), grammaticality judgments (Miller et al., 2001; Wulfeck, Bates, Krupa-Kwiatowski, & Satlzman, 2004), and sentence processing (Montgomery, 2000a, b; Stark & Montgomery, 1995b), and for nonverbal tasks including mental rotation (Johnston & Ellis Weismer, 1983; Miller et al., 2001), scanning speed (Sinninger, et al., 1988), and visual search/discrimination (Schul, et al., 2004; Miller et al., 2001). According to the 'generalized slowing hypothesis' (Kail, 1994), the putative problems in processing speed in SLI has a selective impact on language learning because the operations central to language – such as the parsing and extraction of phonologically and linguistically relevant details in the speech stream – are more time-dependent than other cognitive functions, and as a result are more vulnerable to generalized slowing (Miller at al., 2001).

Findings that performance decrements in SLI typically occur under conditions of greater information processing demands have led to proposals that limitations in general processing capacity may underlie the disorder (Bishop, 1992; Ellis Weismer, 1996; Kamhi, Nelson, Lee, & Gholson, 1985; Johnston, 1991, 1994). Children with SLI perform more poorly than typically developing groups when processing load is increased by, for example, increasing rate of presentation of words to be learned (e.g., Ellis Weismer & Hesketh, 1993, 1996;

Horohov & Oetting, 2004; O'Hara & Johnston, 1997), patterns to be recognized (Fazio, 1998), or increasing the number of relevant pieces of information required to formulate a message or infer an answer (e.g., Bishop & Adams, 1991, see Bishop, 1992; Johnston & Smith, 1989). Such accounts assume that the cognitive system in individuals with SLI adequately handles the processing of individual pieces of information in isolation, but is less efficient in performing operations involving several pieces of information simultaneously (Bishop, 1992). Language learning may be particularly vulnerable to such a deficit because of the sheer number of operations required to learn complex language skills.

One processing account described by Leonard and colleagues (Leonard, 1989, 1998; Leonard, Eyer, Bedore, & Grela, 1991) termed the 'surface hypothesis' proposed a mechanism to account for the grammatical morpheme limitations characteristic of English-speaking children with SLI. According to this view, the general processing capacity limitation in SLI will have an especially profound effect on the joint operations of perceiving grammatical morphemes and hypothesizing their grammatical function. It is argued that many of the grammatical morphemes problematic for children with SLI have short relative duration (i.e., third-person singular *–s* and past tense *–ed* inflections, possessive *'s*, articles, copula and auxillary *be* forms, infinitival *to*, and the complementizer, *that*). In cases of increased processing demands these morphemes are particularly vulnerable, and may be incompletely registered or processed resulting in their loss and overall slower acquisition. These predictions specifically relate to the acoustic characteristics of English; the same processing limitation may lead to another linguistic profile in other languages depending on the particular characteristics of the language (e.g., Leonard & Bortolini, 1998; Leonard, et al., 2001).

1.5.3: Impaired temporal processing

One influential theory of SLI attributes the problem to an inability to process rapidly presented signals, resulting in unstable phonological representations that impair language processing and learning (Tallal, 2000). In a series of studies, Tallal and colleagues (Tallal & Piercy, 1973a, b, 1974, 1975; Tallal & Stark, 1981) reported that children with SLI were unable to detect rapid changes in auditorally presented tones and synthesized speech sounds. For example, SLI groups were found to have great difficulty detecting differences in a two-sound sequence when the interval between the stimuli (intersimulus interval; ISI) was short, but performed at ceiling level when the ISI was long. Children in the control groups, on the other hand, maintained high levels of performance down to ISIs of 8 ms. In addition, an intervention program for children with SLI focusing on intensive training in the discrimination of rapid acoustic transitions in synthetic speech stimuli was found to result in dramatic gains in language abilities (Merzenich, Jenkins, Johnston, Schreiner, Miller, & Tallal, 1996; Tallal, Miller, Beda, Byma, Wang, et al., 1996). Several subsequent studies have gone on to demonstrate SLI deficits in a variety of auditory tasks including detecting a tone that precedes masking (Wright, Lombardino, King, Puranik, Leonard, & Merzenich, 1997), brief gaps in sound bursts (Ludlow, Cudahy, Bassich, & Brown, 1983), and amplitude modulations (Menell, McAnally, & Stein, 1999). Similar results have also been found for children with specific reading impairment (see Farmer & Klein, 1995, for a review).

In recent years, however, the importance, and even the very existence, of temporal processing disorders in SLI have been questioned. Many studies have failed to replicate one of the more crucial findings pertaining to the hypothesis that rapid processing is particularly problematic for children with SLI: the selective impairment on short as compared to long ISIs (e.g., Bishop, Carolyn, Deeks, & Bishop, 1999; Bretherton & Holmes, 2003; van der Lely, Rosen, & Adlard, 2004). In addition, some studies have reported null findings for SLI groups on temporal processing tasks (e.g., Bishop, Adams, Nation, & Rosen, 2005; Sussman, 1993). It is certainly the case that some children with SLI are unimpaired on temporal processing tasks, and that some children with poor auditory temporal processing develop language without difficulty. As Bishop et al. (1999) have pointed out, auditory temporal processing disorders are neither necessary nor sufficient for causing language impairment in children. In a review of the area, Rosen (2003) concluded that auditory deficits appear not to be causally related to language disorders, but occur in association with them.

1.5.4: Impairments of specialized linguistic mechanisms

Another group of theories focus on domain-specific deficits to innate language learning mechanisms in SLI. For example, Gopnick and colleagues (Gopnik, 1990; Gopnik & Crago, 1991) have described the grammatical deficits exhibited by several individuals with SLI in the same family as an inability to formulate implicit grammatical rules. Inflected forms may be memorized as lexical items resulting in their correct and incorrect grammatical use (e.g., use of both ‘a boys’ and ‘a boy’). One of the most fully developed theoretical perspectives in this area is the ‘Extended Optional Infinitive Account’ proposed by Rice and Wexler and colleagues (Rice & Wexler, 1996; Rice, et al., 1995), more recently termed the ‘Extended Unique Checking Constraint’ (Wexler, 2003). Wexler (1994, 2003) argued that young typically developing children go through an ‘optional infinitive stage’ early in language development when they sometimes mark verb tense in main verbs and sometimes use the unmarked (infinitive) form, due to a developmental constraint on the computational system of language that fades over time. By five years of age, typically developing children have moved out of this stage and verb tense errors will be rare. Rice and Wexler reported evidence that the verb morphology errors seen in SLI are characteristic of the ‘optional infinitive stage’. It was suggested that the higher frequency and persistence of errors in this domain of grammar reflects an ‘extended optional infinitive stage’, arising as a result of continued constraints on the computational system of language that may remain indefinitely (Wexler, 2003). Rice (2003) has argued that grammatical tense marking provides a clinical marker of SLI that exceeds the delays in other areas of language, and is independent of nonverbal intelligence (Rice, et al., 2004).

One additional account assuming impaired linguistic mechanisms has been proposed by van der Lely (2004) to describe the subgroup of children with G-SLI (see section 1.1.3) who show evidence of a discrete grammatical deficit. According to the ‘Computational Grammatical Complexity hypothesis’ (a development of the RDDR; see section 1.1.3), children with G-SLI are impaired in the computations underlying hierarchical, structurally-complex forms in one or more component of grammar. Each component, syntactic, morphological, and phonological, has its own hierarchical structural complexity, which have independent and differential effects on sentence processing and production. It is argued that the pervasive deficits in grammatical components characteristic of G-SLI are determined by this structural complexity.

1.6: Notes on Research Methodology

As indicated throughout this chapter, the language abilities of children with SLI lag behind those of same-age peers in many ways. It can be argued that comparisons between children with SLI and chronological age controls may reveal little about the specific nature of SLI for two reasons (van der Lely & Howard, 1993): SLI groups tend to perform below chronological age-control children on the majority of tasks in which linguistic processing is involved, which provides little information regarding relative deficits. Secondly, it is unclear how the differing language abilities of these groups may affect performance making group differences, should they occur, difficult to interpret. One solution to this problem has been to compare children with SLI to younger children matched for language abilities. The performance of a language-matched control group should reflect the attainment of individuals with language abilities similar to that of the SLI group. SLI deficits in comparison to this group, then, point to select areas of disproportionate impairment in relation to general levels of language development providing clues as to the aetiology of the disorder.

Problems with the use of a control group matched for language abilities have also been raised, however. One difficult issue is the identification of similar language abilities. Language is multi-dimensional with differing patterns of variation and interaction among the component skills, yet most studies employ one measure of language for the purpose of matching linguistic skill such as receptive grammar (e.g., Montgomery, 1995b) or receptive vocabulary (e.g., Norbury, et al., 2002). It is highly unlikely that any two individuals with similar performance on one measure will be matched on linguistic skills across the board, raising the possibility that some linguistic ability other than that on which the matching was based differentially affects the dependent variable (Plante, Swisher, Kiernan, & Restrepo, 1993). A greater potential problem lies in the fact that the language-matched control children are inevitably younger than the children with SLI to whom they are matched. This introduces extraneous age effects related to developmental differences and rates of growth in, for example, cognitive, physical, or social development (Mervis & Robinson, 2003; Plante et al., 1993). In this context, null effects are particularly difficult to interpret (Edwards & Lahey, 1998; Ellis Weismer & Hesketh, 1996). It is unknown whether the relative developmental immaturity of the language-matched group prevented their better performance despite underlying superiority in the skill measured, or whether, in fact, the skills are equivalent between the groups.

In order to address the problems outlined above, studies typically employ multiple control groups and measurements. By using more than one comparison group and measuring several features of language, it is possible to determine more precisely how children with SLI differ from typically developing children (Leonard, 1998). In addition, the use of multiple measures of a construct provides a more reliable and robust assessment for comparison between groups. One other method of accounting for differences between typically developing and impaired groups is to adjust scores statistically using a test presumed to tap the key differences as a covariate in an analysis of covariance (ANCOVA). Plante et al. (1993) recommend controlling for language level in comparisons of SLI and age-matched groups (e.g., Munson, Edwards, & Beckman, 2005), but the opposite technique is also employed: adjustments are made using measures of nonverbal abilities in comparisons of SLI and younger, language-matched groups (e.g., Edwards & Lahey, 1998). It should be noted that the use of the ANCOVA in this manner is a matter of some debate (Miller & Chapman, 2001).

In the studies reported in the present thesis, many of the practices outlined above that are commonly used as ‘best-practice’ in current research in this area were employed. Specifically, two control groups were included, age-matched and language-matched. Multiple measures of language, short-term and working memory were employed to provide robust estimates of these constructs. Where appropriate, statistical adjustments for differences in nonverbal and language abilities were included in data analyses in order to assist in the interpretation of the results.

1.7: The Research in this Thesis

The primary aim of this thesis is to further examine immediate memory processes in SLI. The chapters are organized into two main sections: Chapters 2, 3, and 4 explore short-term and working memory across domains in SLI, while chapters 5 and 6 investigate the nonword repetition deficit in SLI. Chapter 2 provides an initial description of the performance of a group of school age children with SLI on standardized measures of verbal short-term memory including nonword repetition, visuospatial short-term memory, and verbal working memory. Chapter 3 examines visuospatial immediate memory in SLI by comparing the children with SLI to two groups of typically developing children matched either for age or language abilities on experimental versions of visuospatial short-term and working memory tasks. Chapter 4 evaluates possible domain specificity in storage and processing deficits in SLI by comparing the groups on complex memory tasks systematically varying verbal and visuospatial demands, as well as independent storage and processing measures.

The nonword repetition deficit in SLI is examined in chapters 5 and 6. One focus of these chapters is to evaluate claims that nonword repetition is an index of verbal short-term memory, and that poor nonword repetition in SLI reflects impaired verbal short-term storage. Chapter 5 compares the groups on two commonly employed nonword repetition tasks that differ in the extent to which factors other than short-term memory may constrain performance. Chapter 6 contrasts group performance on the recall of items that pose an equivalent memory load but differ in other potentially important respects such as coarticulation and duration: the repetition of matched syllable sequences presented either as multisyllabic nonword forms or monosyllabic nonword lists. Chapter 7 draws together all of the findings and discusses them in relation to cognitive mechanisms that may underlie SLI.

Chapter 2

Short-term and Working Memory in Specific Language Impairment

Section 1.4 reviewed evidence pertaining to immediate memory impairments in children with a common developmental pathology, Specific Language Impairment (SLI) characterized by unexpected difficulty learning language. In recent years, the magnitude of these memory deficits in children with SLI has led to the suggestion that they may play a primary role in the developmental language disorder (e.g., Bishop, et al., 1996; Conti-Ramsden, 2003a; Ellis Weismer, 1996; Gathercole & Baddeley, 1990a; Montgomery, 1995a, 2000b). The majority of studies, however, have focused either on verbal short-term memory, or working memory. The aim of the present study was to investigate the extent to which deficits in both verbal short-term and working memory may co-occur in a group of children with SLI.

As discussed in section 1.2, short-term and working memory both involve temporary storage, but are distinguished by whether or not significant processing activity is required concurrently. Short-term memory tasks impose storage but minimal processing demands; verbal versions typically involve serial recall of words, letters or digits (e.g., Conrad & Hull, 1964), whereas visuospatial versions involve the retention of either visual patterns or sequences of movements (e.g., Smyth & Scholey, 1996; Wilson et al., 1987). In contrast, working memory tasks engage the participant in significant processing activity in addition to storage, typically using complex memory span paradigms. An example of a verbal complex memory task is listening span, in which the participant is asked to make a meaning-based judgment about each of a series of sentences, and then remember the last word of each sentence in sequence (e.g., Daneman & Carpenter, 1980).

It is widely accepted that performance on verbal short-term memory and complex memory span tasks reflect distinct systems. According to the working memory model advanced originally by Baddeley and Hitch (1974) and reviewed in section 1.2, performance on short-term memory tasks involving the serial retention of verbal material is supported by the phonological loop. This consists of a phonological short-term store subject to rapid decay, and a subvocal rehearsal mechanism that can be used to maintain phonological representations within the store (Baddeley, 1986). Performance on verbal complex memory tasks, on the other hand, is believed to tap both the phonological loop (for storage), and the more flexible processing resources of the central executive (Baddeley & Logie, 1999; Duff & Logie, 2001; Lobley, Baddeley, & Gathercole, 2005). Other theorists have suggested that complex memory span paradigms tap a general working memory system constrained by a limited attentional resource that is separate from short-term memory (e.g., Barrouillet, Bernadin, & Camos, 2004; Cowan, 1995, 2001; Engle, Kane, et al., 1999).

As reviewed in detail in section 1.4, studies of immediate memory in SLI have focused mainly on two aspects – verbal short-term memory and working memory. In a study of verbal short-term memory deficits in children with language impairment, Gathercole and Baddeley (1990a) reported that a group of children with SLI were significantly more impaired than younger control children matched for language abilities on tasks requiring the immediate memory of phonological forms. The deficit was particularly marked in the nonword repetition paradigm, in which the child attempts to repeat unfamiliar phonological forms such as /wʊgə'læmɪk/. The finding of impaired nonword repetition in children with SLI has been replicated subsequently in many independent studies (Bishop et al., 1996; Conti-Ramsden, 2003b; Dollaghan & Campbell, 1998; Edwards & Lahey, 1998; Ellis Weismer, et al., 2000; Montgomery, 1995a; Sahlen, et al, 1999). The nonword repetition deficits in SLI are highly heritable, and provide a useful phenotypic marker of the disorder (Bishop et al., 1996). A chromosomal abnormality linked directly with nonword repetition deficits in SLI has recently been identified on chromosome 16q (SLI Consortium, 2002, 2004).

Gathercole and Baddeley (1990a) argued that the nonword repetition deficit in SLI reflects an underlying impairment of verbal short-term memory. Two lines of evidence link nonword repetition to short-term memory. First, nonword repetition ability has consistently been found to be closely associated with more traditional short-term memory measures such as digit span (see Gathercole, et al., 1994; Baddeley, Gathercole, et al., 1998, for reviews). Second, several studies have shown a clear advantage for immediate memory of familiar over unfamiliar words (Gathercole, et al., 1997; Papagno, Valentine, & Baddeley, 1991; Vallar & Baddeley, 1984), and for nonwords rated as high versus low in wordlikeness (Gathercole, 1995; see also, Gathercole, et al., 1999). These findings indicate that immediate memory for words and to a lesser extent familiar nonwords is facilitated by the activation of long-term lexical knowledge. As such an advantage is not present for unfamiliar nonwords, measures of nonword repetition that include nonwords with low levels of wordlikeness will necessarily rely to a greater extent on the creation of a representation and immediate short-term storage of the novel phonological form.

Other researchers have suggested that nonword repetition taps other cognitive processes including lexical knowledge (Snowling, et al., 1991), phonotactic probability (Edwards, Beckman, & Munson, 2004), phonological sensitivity (e.g., Bowey, 1996; Metsala, 1999), and output phonology (e.g., Sahlen et al., 1999; Wells, 1995)

Drawing on converging evidence from studies of normal adults, typically-developing children and neuropsychological patients showing close links between verbal short-term memory and the learning of the sound structures of new words, Baddeley, Gathercole, et al. (1998) proposed that the primary role of short-term memory is to support learning of the phonological structure of language. These researchers suggested that the phonological representations of brief and novel speech events generated in short-term memory mediate the construction of more durable phonological entries in the lexical store of long-term memory. By this account, the severe deficits of verbal short-term memory in individuals with SLI (as manifest in nonword repetition) are a primary cause of their impairments in vocabulary learning.

A second area of immediate memory deficit in SLI is verbal working memory. A small number of studies have reported substantial deficits on verbal complex memory tasks, tapping working rather than short-term memory, for groups with SLI (Ellis Weismer, et al., 1999; Montgomery, 2000a, b). Montgomery (2000a) suggested that the reduced complex memory span reflects a general information-processing inefficiency in SLI that constrains language development. According to this view, the ability to comprehend and produce language is dependent on the ability to actively maintain and integrate linguistic information within working memory. Limitations in working memory capacity result in trade-offs within and across language domains such that increased demands in syntactic or semantic processing, for example, result in errors in these or other domains (Ellis Weismer, 1996).

As reviewed in section 1.4.2, visuospatial short-term memory has received little attention in investigations of SLI. A few studies have yielded evidence that the memory deficit in SLI may extend to the visuospatial domain (Doehring, 1960; Montgomery, 1993; Poppen, et al., 1969; Wyke & Asso, 1979). It should be noted however that SLI deficits were found in these studies only in the condition in which a delay was imposed prior to responding. The children with SLI were not impaired in the immediate recall condition, which is the more conventional paradigm used in this research area.

Phonological awareness - the ability to analyse and manipulate sound and syllable units - is a further cognitive skill associated with both short-term memory and learning abilities. There is considerable evidence indicating that phonological awareness is reduced in children with SLI (e.g., Bishop & Adams, 1990; Catts, 1993; Stackhouse, 1997). These studies typically include tasks that involve recognizing or producing phonologically similar units, segmenting words and syllables, or blending phonological elements. These tasks require both the short-term retention of stimuli and phonological analysis of constituent phonemes. Some researchers have suggested that phonological memory and awareness measures tap a common phonological coding or processing substrate (e.g., Bowey, 1996; Dufva, Niemi, & Voeten, 2001; Griffiths & Snowling, 2002; Passolunghi & Siegel, 2001; Wagner, Torgeson, Laughon, Simmons, & Rashotte, 1993). An alternative view is that phonological memory and awareness tasks tap distinct mechanisms involving phonological loop and metalinguistic analysis respectively, but which are both constrained by the adequacy of phonological processes (Alloway, Gathercole, Willis, & Adams, 2004; Hecht, Torgesen, Wagner, & Rashotte, 2001; Muter & Snowling, 1998).

The present study investigated the performance of a group of children with SLI aged 7 to 11 years of age on standardized assessments of short-term memory, working memory, and phonological awareness with the aim of establishing the extent to which deficits in verbal short-term memory, working memory, and phonological awareness co-occur in children with SLI. The extent, magnitude and correspondence of potential deficits in these areas addresses a series of key issues related to the theoretical understanding of SLI. One issue relates to the proposed contribution of both verbal short-term and working memory to language development. Verbal short-term memory has been linked specifically with vocabulary acquisition (Gathercole, et al., 1997; Gathercole, et al., 1992), whereas working memory has been more generally associated with learning difficulties, including literacy (Gathercole, Alloway, Willis, & Adams, 2005). In addition, individual differences analyses have revealed developmental dissociations between verbal short-term and working memory (Swanson, 2004). A second issue concerns the relation between deficits in phonological awareness and verbal short-term memory. Comparable deficits in both areas (e.g., Bowey, 1996; Metsala, 1999) would be consistent with the view that the core deficit is a single factor that underlies both types of task (such as phonological processing). Dissociable performance on the memory and awareness measures, on the other hand, would point to differentiation between these areas of cognitive deficit in SLI.

A further aim of the study was to broaden the assessment of immediate memory function to include visuospatial short-term memory, which represents a further sub-component of memory in the Baddeley and Hitch (1974) model of working memory. An across-the-board deficit in children with SLI extending across verbal short-term memory, complex memory span and visuospatial short-term memory would be indicative of a domain-general rather than a specifically verbal deficit in immediate memory.

2.1: Method

2.1.1: Participants

Children were recruited from language units (*n*=17) and special schools (*n*=3) in urban areas of the North-East of England over a four-month period. All of these children were receiving individual daily support to address their specific speech and language needs, and the majority were integrated into mainstream classrooms for some portion of their day. The following inclusionary criteria for SLI were employed. i) A standard score greater than 85 on a test of nonverbal reasoning (*Raven's Coloured Matrices*; Raven, Court & Raven, 1986). ii) Scores of at least 1.25 standard deviations below average on at least two of four core language measures, with a score of at least 1 *SD* below average on at least one receptive measure. The receptive measures were the *British Picture Vocabulary Scales, 2^nd^ edition* (BPVS-II, Dunn, Dunn, Whetton & Burley, 1997) and the *Test for Reception of Grammar* (TROG, Bishop, 1982). The expressive measures were the *Expressive Vocabulary Test* (EVT, Williams, 1997), and the *Recalling Sentences* subtest of *Clinical Evaluation of Language Fundamentals – 3 UK* (CELF, Semel, Wiig, & Secord, 1995). (iii) A standard score greater than

80 on the *Goldman Fristoe Test of Articulation 2* (GFTA-2, Goldman & Fristoe, 2000). (iv) A score greater than 131 on the *Children's Communication Checklist* (Bishop, 1998), indicating no pragmatic impairment. In addition, children were excluded if they had a diagnosis of ADD/ADHD, Autism Spectrum Disorder, hearing impairment, or if their native language was not English. A total of 20 children (14 males, 6 females) between the ages of 6;9 and 11;10 (*M*=9.09, *SD*=1.50) met these criteria from an initial pool of 60. Five children were under eight years of age (*M*=7.27, *SD*=0.44), and 15 were over eight years (*M*=9.70, *SD*=1.20).

The language measures used in the present study were selected on the basis of their widespread use for the identification of children with SLI (e.g., Botting & Conti-Ramsden, 2001; Bishop et al., 1996; Bishop, Bright, James, Bishop, & van der Lely, 2000). It is clear though, that sentence imitation tasks such as the Recalling Sentences subtest employed here not only tests language ability, but also are linked to short-term memory (Blake, Austin, Cannon, Lisus, & Vaughan, 1994; Willis & Gathercole, 2001). In order to ensure that participant selection decisions were based on language rather than memory skills, additional expressive language tests were administered when *Recalling Sentences* was one of the two language tests on which inclusion was based (*n*=8). As an added control, these participants completed the two additional expressive subtests of the *CELF – 3UK* required to compute the test's *Expressive Language Score* for their age (*Word Structure* (*n*=3) or *Sentence Assembly* (*n*=5), and *Formulating Sentences* (*n*=8)). In all cases, the *Expressive Language Score* was greater than 1.25 *SD* below average.

2.1.2: Procedure

Each child was tested individually in a quiet room in school for four half-hour weekly sessions at the time of recruitment. In addition to the language screening measures listed above, each child was also tested on the following tests: the *Working Memory Test Battery for Children* (WMTB-C; Pickering & Gathercole, 2001), the *Visual Patterns Test* (VPT; Della Sala, Gray, Baddeley, & Wilson, 1997), and the *Alliteration* and *Spoonerisms* subtests of the *Phonological Assessment Battery* (PhAB; Frederickson, Frith & Reason, 1997). No more than two standardized tests or subtests were completed in one session, receptive measures preceded expressive measures, and language measures preceded phonological processing measures, which preceded memory measures. The subtest order recommended by the standardized test was followed within each test. Fifteen of the participants completed the *Children's Test of Nonword Repetition* (CNRep; Gathercole & Baddeley, 1996) in a single half hour session within six months of the original sessions. Results from the CNRep are reported here for purposes of comparison, but are discussed in more detail in chapter 5.

The WMTB-C (Pickering & Gathercole, 2001) was designed to provide multiple assessments of each of the three components of the Baddeley and Hitch (1974) working memory model, using where possible tasks that have been validated as measures of each component (Gathercole & Pickering, 2000). The battery includes four measures of verbal short-term memory, three measures of visuospatial short-term memory, and three working memory span measures. In the working memory measures, the children were engaged in some form of processing activity such as understanding a sentence or counting dots, and simultaneously maintained certain aspects of this processing for subsequent recall. The processing portions of these tasks are believed to tap the flexible resources of the central executive and the storage requirements to impose a load on the phonological loop (e.g., Baddeley & Logie, 1999). The CNRep (Gathercole & Baddeley, 1996) was included in the present study both to provide a complete assessment of verbal short-term memory as recommended in the WMTB-C, and data comparable to previous reports of SLI deficits on this task (e.g., Bishop et al., 1996; Gathercole & Baddeley, 1990a).

Verbal short-term memory. The digit recall, word list recall, and nonword list recall tests involve the presentation of a sequence of digits, words, or nonwords that the child is required to recall in correct serial order. Following a practise session, a maximum of six lists is presented at each length. List length is increased by one if the child recalls four lists at that length correctly, and continues to a maximum length of nine items. If the first four trials at each length are correct, the child is credited with correct recall of all six lists at that length and the next list length commences. Testing commences with one item, and continues until three lists of a particular length are recalled incorrectly. The number of lists correctly recalled is scored, and standard scores (with a mean of 100 and a standard deviation of 15) calculated.

Digit lists are random constructions without replacement from the digits ranging from 1 to 9, spoken at a rate of one digit per second. The word lists are monosyllabic words with a consonant-vowel-consonant structure, and no stimuli are repeated. The nonwords have the same structure, and were created using the same pool of phonemes as the words used in the word list recall subtest. The words and nonwords, which are spoken at a rate of one syllable per second, must be recalled with full accuracy (i.e., with all three phonemes correct) and in the correct serial position. Credit was given for phoneme substitutions when the substitution constituted the child’s habitual articulation pattern for that phoneme.

In the *word list matching* test, the child hears two lists of identical monosyllabic words and must indicate if the words were presented in the same serial order by answering ‘yes’ or ‘no’. Test trials begin with list lengths of two words, and increase by one word following the span procedure outlined above. Note that the forced choice format of this subtest increases the likelihood of ‘guessing correctly’ but minimizes production demands.

Test scores on the four verbal short-term memory tasks outlined are summed to form a verbal short-term memory composite score, and standardized scores (with a mean of 100 and standard deviation of 15) calculated based on norms provided by Pickering and Gathercole (2001).

The CNRep (Gathercole & Baddeley, 1996) involves the presentation of 40 non-words, divided equally into two-, three-, four- and five-syllable items that the child is required to repeat (Appendix 1). Half of the non-words contain consonant clusters (e.g., /'blɒntə'steɪpɪŋ/) and are designated ‘complex’ and the remainder have only singleton consonants and are designated simple (e.g., /wʊgə'læmɪk/). The non-words are presented in a fixed random order by audiotape recording, and the test is scored immediately with each item judged as correctly or incorrectly repeated. Typical English stress patterns are used in the presentation. Raw scores (number of correct repetition attempts) and standardized scores are calculated (Gathercole & Baddeley, 1996; Simkin & Conti-Ramsden, 2001).

Visuospatial short-term memory. In the *block recall* test, the presenter taps a sequence of cubes with a finger on a specifically designed board that has

9 randomly located cubes. The child's task is to repeat the sequence in the same order. Testing begins with a single block tap, and increases by one additional block following the span procedure outlined above. In the *mazes memory* test, the child views a two-dimensional line maze with a path drawn through the maze. The test administrator traces the line with his/her finger in view of the child. The same maze is then shown to the child without the path, and the child is asked to recall the path by drawing it on the maze. Each maze is presented for three seconds. Maze complexity is increased by adding additional walls to the maze, following the span procedure outlined above. For each of these tests, the number of trials correctly repeated is scored, and standard scores calculated as outlined above.

In the *Visual Patterns Test* (Della Sala et al., 1997), the child views and then recalls two-dimensional grids composed of filled (black) and unfilled (white) squares. Each grid is viewed for three seconds, and the child is then presented with an empty grid in which he or she has to mark the filled squares in the correct pattern. The complexity of the grid is increased every three trials until the child is unable to recall the pattern accurately on any of the three trials at one level. Standard scores were calculated for this test, using the Pickering and Gathercole (2001) norms.

Test scores on the three visuospatial tasks outlined are summed to form a visuospatial short-term memory composite score, and standardized scores calculated as outlined above.

Working memory. In the *listening recall* test, the child listens to a short sentence with subject-verb-object word order, and early developing vocabulary appropriate for young children. Two examples of such sentences are 'Lions have four legs' and 'Pineapples play football'. The child judges the veracity of the sentence by responding "yes" or "no", and then recalls the final word of the sentence. Test trials begin with a single sentence, and increase by a single sentence following the span procedure outlined above. Correct serial order must be maintained in the final word recall in order for the response to be considered accurate. In the *counting recall* test, the child views a display booklet consisting of pages each showing an array of three, four, five, six or seven red dots. The child is required to count the number of dots presented in a series of arrays (saying the total number aloud), and to recall subsequently the dot tallies in the order that the arrays were presented. Test trials begin with a single array of dots, and increase by one further array following the span procedure outlined above. The *backward digit recall* subtest is identical to the digit recall test in all respects except that the child is required to recall the sequence of spoken digits in reverse order. Practice trials are given in order to ensure that the child understands the concept of reverse. For each of these subtests, the number of trials correct is counted, and standard scores calculated as outlined above.

Test scores on the three working memory tasks outlined are summed to form a working memory composite score, and standardized scores calculated as outlined above.

Phonological awareness. The *alliteration* test involves the child identifying words that share the same initial sound. For children younger than 8;11 years (*n*=5), the format with pictures was selected in order to minimize memory demands. The child views a picture card with three pictures. The tester says the word for each picture while pointing to it, and then says the three words again. The child is required to say the two words (or point to the two pictures of words) that share the same initial sound. The format without pictures involves the tester reading out the three words, and the child saying the two words that have the same initial sound. In Part 1 of the s*poonerisms* test, the child is required to replace the first sound of a word with a new sound (e.g., ‘cat’ with a /f/ gives ‘fat’). Part 2 is administered to children over the age of seven years, and only if they score on part one. In Part 2, the child is asked to exchange the initial sounds in two words (e.g., ‘sad cat’ gives ‘cad sat’). The trials within each part are discontinued after three consecutive errors or three minutes have elapsed since the presentation of the first item. For each of these tests, the number of trials correct is counted, and standard scores (with a mean of 100 and a standard deviation of 15) calculated. A composite phonological awareness score was calculated from the mean of the two subtest standardized scores.

2.2: Results

2.2.1: Descriptive Statistics

The descriptive statistics for the language screening measures are shown in Table 2.1. Group means for the receptive vocabulary (BPVS-II; Dunn et al., 1997), receptive language (TROG; Bishop, 1982), and expressive vocabulary (EVT; Williams, 1997) measures were approximately 1.25 *SD* below the standardized mean, and more than 2 *SD* below the mean for Recalling Sentences (Semel et al., 1995). The proportion of children who scored below 81 was similar for three of the measures (BPVS-II, TROG, EVT), and highest for the Recalling Sentences measure. Individual language profiles conformed closely to the group pattern with twelve participants scoring more than 1.25 *SD* below the mean on 3 or 4 of the language measures. It should be noted that the poor performance of the participants on the sentence repetition task relative to the other language measures may reflect the significant language and memory load imposed by the task.

Table 2.1

Descriptive statistics for screening measures (n=20)

Measure	*M*	*SD*	Range (min-max)	Proportions[c] A	Proportions[c] B	Proportions[c] C
Raven[a]	105.85	9.89	90-125	0.00	0.00	0.00
GFTA[a]	90.95	4.61	82-99	0.00	0.15	0.00
BPVS-II[a]	79.65	9.05	58-94	0.60	0.65	0.45
EVT[a]	79.00	10.64	57-106	0.65	0.80	0.55
TROG[a]	80.00	11.31	63-109	0.60	0.80	0.60
Recalling Sentences[b]	3.45	1.05	3-7	0.95	0.95	0.95

Note. GFTA – Goldman Fristoe Test of Articulation; BPVS-II – British Picture Vocabulary Scale, 2nd ed.; EVT – Expressive Vocabulary Test; TROG – Test for Reception of Grammar

a - Standardized scores with a mean of 100 and standard deviation of 15.

b - Scaled score with a mean of 10 and standard deviation of 3.

c - Proportions: A – Proportion of sample meeting language criterion of scoring at least 1.25 *SD* below average (i.e., scoring below 81); B – Proportion scoring at least 1.00 *SD* below the mean on this test (i.e., scoring below 86); C – Proportion scoring at least 1.5 SD below the mean on this test (i.e., scoring below 79)

2.2.2: Memory and phonological awareness measures

Performance on the memory and phonological awareness measures is summarised in Table 2.2. On individual tests, group means ranged from 1.0 to 1.2 *SD* below the standardized mean for three of the verbal short-term memory measures (digit recall, word recall, and nonword recall), and were much lower on the CNRep, on which performance was more than 4 *SD* below the mean, with standard scores below 65 for every child in the group completing this task. Group means for two of the working memory tasks were approximately 1 *SD* below the standardized mean (listening recall, backward digit recall), and the standardized mean for the counting recall task was markedly lower (-1.9 *SD*). The composite score for verbal short-term memory was 1.2 *SD* below the mean, and the working memory composite was 1.7 *SD* below the mean. Mean scores for all of the visuospatial short-term memory measures, visuospatial short-term memory composite, phonological awareness measures and composite, as well as word list matching were within 1 *SD* of the mean.

Table 2.2

Descriptive statistics for short-term memory, working memory and phonological awareness measures (n=20)

Measure[a]	*M*	*SD*	Range (min-max)	Proportions[c]	
				A	B
Memory:					
Verbal STM:					
Digit recall	84.45	11.48	69-104	0.60	0.35
Word list match	96.85	14.53	70-137	0.20	0.10
Word recall	82.60	8.47	66-97	0.70	0.30
Nonword recall	81.95	13.47	59-101	0.50	0.45
Composite Verbal STM	81.90	11.02	65-111	0.70	0.40
CNRep[b]	51.47	7.09	46-65	1.00	1.00
Visuospatial STM:					
Block recall	87.60	17.17	59-124	0.45	0.25
Mazes memory	90.55	13.04	67-130	0.25	0.15
Visual patterns	91.60	12.81	68-111	0.40	0.20
Composite VSSP STM	86.45	15.65	58-130	0.50	0.30
Working Memory					
Listening recall	85.85	12.70	55-103	0.30	0.20
Counting recall	71.35	11.38	55-95	0.90	0.75
Backward digit	84.85	10.12	70-105	0.55	0.25
Composite WM	74.50	8.39	55-90	0.95	0.75

table continues

Phonological Awareness					
Alliteration	90.35	8.54	77-100	0.33	0.05
Spoonerisms	87.55	9.42	69-107	0.43	0.15
Composite PA	88.95	7.97	73-103.50	0.38	0.10

Note. STM – short-term memory; VSSP – visuospatial; WM – working memory; PA – phonological awareness; CNRep – Children's Test of Nonword Repetition

a - All scores are standardized scores with a mean of 100 and *SD* of 15.

b - *n*=15 for this measure

c - Proportions: A – Proportion of sample scoring at least 1.0 *SD* below the mean on this test (i.e., scoring below 86); B - Proportion of sample scoring at least 1.5 *SD* below the mean on this test (i.e., scoring below 79).

The composite scores of the WMTB-C provide a robust estimate of performance because they are based on multiple measures of a construct. However, the performance of the SLI group was markedly lower on one measure of working memory, counting recall, than performance on the other two working memory measures. Standard scores of below 86 on at least two of the working memory measures did characterize 70% of the sample (*n*=14), indicating that for the majority of participants a pattern of low performance was established across multiple complex memory span measures.

For the present purposes, 'deficit' is defined as a score of more than 1 *SD* below the mean of the standardization sample corresponding to an effect size of 1.0, conventionally considered to be large (Cohen, 1988). The proportion of participants obtaining scores below 86 (using our deficit criteria) and below 79 (corresponding to 1.5 *SD* below the standardized mean) on each of the working memory measures is included in Table 2.2. For the purpose of comparison, the same proportions for each of the language screening and phonological awareness measures are shown in Table 2.1 and Table 2.2, respectively. One striking finding was that 95% of the participants scored in the deficit range on the working memory composite. This proportion is higher than for any of the other language measures with the exception of the Recalling Sentences subtest, which, as noted above, has a high memory load. In addition, 70% of the children scored in the deficit range on the verbal short-term memory measure. Fifty percent of the participants scored in the deficit range on the visuospatial short-term memory composite, and 38% on the phonological awareness measure.

In order to determine the frequency with which the short-term and working memory profiles of the SLI group would occur in a typically developing population, the performance of the SLI group on the memory measures was compared to the 636 children who participated in the standardization sample of the WMTB-C (Pickering & Gathercole, 2001), and who had no special education needs (mean age 9.1 years, *SD* =3.0, *R*=4-16 years). Likelihood ratios were computed corresponding to a cut-off of 1 *SD* below the standardized mean on the WMTB-C composite scores. A likelihood ratio expresses the odds that a given test result would be expected in a member of a population who is affected by a condition (e.g., SLI) as opposed to a member without the condition (Sackett, Haynes, Guyatt, & Tugwell, 1991). A likelihood ratio is calculated by taking the proportion of participants in the affected group who score at a set criterion on a test and comparing it to the proportion of participants in the unaffected group who score at this level. The ratio represents the extent to which the incidence of particular profiles is increased in the affected group relative to the unaffected group. The associated probability values represent the probability that an individual with a particular profile drawn randomly will be a member of the affected group.

The likelihood ratios summarised in Table 2.3 were calculated for short-term and working memory profiles defined by cut-off scores of 86, equal to or greater than 1 *SD* below the mean. The rate of incidence of obtaining a working memory composite score of less than 86 was 9 times greater for the SLI group than the standardization sample. The post-test probability that an individual with this profile drawn at random would be a member of the SLI group is .90. The corresponding likelihood ratios for verbal short-term memory and visuospatial scores below 86 were 5.28 and 3.41, respectively (with corresponding post-test probabilities of .84 and .77).

Table 2.3

Likelihood ratios analysis for WMTB-C composite scores

Component	SLI group (n=20)		Comparison group[a] (n=636)		Likelihood Ratio[a]	p
	n	Proportion	n	Proportion		
Working Memory	19	0.95	69	0.11	8.76	0.90
Verbal STM	14	0.70	86	0.14	5.18	0.84
Visuospatial STM	10	0.50	93	0.15	3.41	0.77

Note. STM – short-term memory; p – probability

a - Using standardization sample as comparison

One important issue concerns whether the short-term memory, working memory, and phonological awareness deficits of the children with SLI exceeded the language impairment that formed the basis for their diagnosis. This was investigated by obtaining language-adjusted standard scores in each area of assessment. Language ages were calculated from the raw score of the BPVS-II (Dunn et al., 1997), and this age rather than the chronological age was used as the basis for calculating the standard scores on the WMTB-C (Pickering & Gathercole, 2001), the CNRep (Gathercole & Baddeley, 1996), and the PhAB (Frederickson et al., 1997). Thus, language-adjusted standard scores of 100 would indicate levels of performance commensurate with language abilities. It should be noted that there are known difficulties with the use of age equivalent scores that may have been exacerbated in the two-step process across tests employed here (see Bishop, 1997, p. 28). Thus, the present results provide only a rough estimate of performance commensurate with language level.

The language-adjusted standard scores are summarized in Table 2.4. Consider first the WMTB-C scores. Mean language-adjusted working memory scores were low, at 88.40. Verbal short-term memory scores were in the low average range (90.75), and group performance on the visuospatial short-term memory measure was appropriate for language age (101.05). Language-adjusted scores on the CNRep showed a very large deficit, with a group mean of 66.13. Finally, language-adjusted scores on the PhAB were at average levels (94.78). For each of these five language-adjusted measures, one-sample *t*-tests were computed on the means against the expected value of 100, with a Bonferroni correction for multiple comparisons (α=.01). Verbal short term memory, *t*(19)=-3.046, *p*<.01, working memory, *t*(19)=-3.029, *p*<.01, and CNRep scores, *t*(14)=-7.902, *p*<.01 were significantly lower than the expected values. No significant differences were found for the remaining measures (*p*>.01, all cases).

Table 2.4

Language-adjusted standard scores for short-term memory, working memory and phonological awareness (n=20)

Component Score[a]	*M*	*SD*	*t*[b] (*df*=19)	*p*[c]
Verbal STM	90.75	13.58	3.046	.01*
Visuospatial STM	101.05	22.82	0.206	.84
Working Memory	88.40	17.13	3.029	.01*
CNRep[d]	66.13	16.60	7.902	.001*
Phonological Awareness	94.78	9.13	2.561	.02

Note. STM – short-term memory; CNRep – Children's Test of Nonword Repetition

a - Language-adjusted standardized scores with a mean of 100 and *SD* of 15.

b - *t*-statistic for one-sample *t*-test using test value mean of 100.

c - p-value for *t*-statistic

d - *n*=15 for this measure; *df*=14

2.3: Discussion

This study has established substantial deficits in immediate memory for verbal material in a sample of children with SLI. The most marked impairments were on measures of working memory and verbal short-term memory. The magnitude of these deficits exceeded the children’s criterial language impairments. Deficits were also found on measures of visuospatial short-term memory for half of the group, and on phonological awareness for approximately 40% of the children.

Consider first the verbal short-term memory profiles of the children with SLI. Verbal short-term memory deficits were present in a large majority of the children with SLI on several standard measures of short-term memory including the serial recall of digits, words and nonwords. The findings are consistent with the proposal that an impairment of short-term memory may be one contributing factor to the vocabulary learning difficulties in SLI (Baddeley, Gathercole, et al., 1998; Gathercole & Baddeley, 1990a). Baddeley, Gathercole et al. suggested that short-term memory plays an important role in learning new words by generating a phonological representation of brief and novel speech events thereby mediating the creation of a phonological entry within the long-term lexical store.

Very large impairments were found for one particular measure of verbal short-term memory, nonword repetition, replicating many previous studies (e.g., Bishop et al., 1996; Dollaghan & Campbell, 1998; Gathercole & Baddeley, 1990a). It has previously been argued that the nonword repetition deficit in SLI reflects an underlying deficit in verbal short-term memory (Baddeley, Gathercole, et al., 1998; Gathercole & Baddeley, 1990a). In the present study, however, nonword repetition was more sensitive to the deficit in SLI than serial recall, a more conventional measure of short-term memory (see also, Conti-Ramsden, 2003b). It therefore seems likely that the nonword repetition deficit in SLI does not originate solely from an impairment of verbal short-term memory. Other factors that have been suggested to influence nonword repetition include input and output phonological processes (Sahlen et al., 1999; Snowling, et al., 1991; Wells, 1995), and pre-existing lexical knowledge (Gathercole, 1995; Gathercole, Willis, & Baddeley, 1991) each of which is known to be impaired in SLI. The discriminating power of the nonword repetition paradigm may therefore reflect its sensitivity to multiple indices of language impairment including impairment of verbal short-term memory, rather than a single causal factor. The possible influence of factors additional to short-term memory on nonword repetition performance in both children with SLI and typically developing groups is evaluated more systematically in the studies reported in chapters 5 and 6 of this thesis.

In addition to impairments in short-term memory, deficits in working memory were highly consistent across our sample, and present in all of the children except one. On the basis of other findings from samples with developmental impairments of memory, it seems likely that the poor verbal short-term and working memory function in this group reflects parallel deficits rather than a single underlying disorder. First, short-term memory deficits alone do not appear to result in SLI. In a recent study, children with a history of very poor verbal short-term memory that extended between 4 and 8 years of age and working memory skills in the low average range were found to have age-appropriate language abilities four years later (Gathercole, et al., 2005). Second, and conversely, children with learning difficulties in reading and mathematics are typically characterised by poorer working memory than verbal short-term memory function (Gathercole, et al., 2005; Swanson, 2004). Thus, an impairment of working memory is not invariably accompanied by a deficit in verbal short-term memory, or *vice versa*. It should be noted that although the diagnosis of SLI focuses on language deficits, individuals with SLI commonly experience learning difficulties of a comparable magnitude across all scholastic domains, including mathematics (Fazio, 1996; Donlan & Gourlay, 1999; Arvedson, 2002) and literacy (Catts, et al., 2002; Bishop & Adams, 1990; Flax, et al., 2003).

The present data indicate therefore that the majority of the children with SLI in the present study faced double memory jeopardy, with deficits in temporary memory systems closely linked to learning including both verbal short-term and working memory. In line with the links between memory and language outlined in section 1.3, it is suggested that the poor short-term memory function of most children in this group compromises their abilities to learn the phonological forms of language, and that their working memory limitations constrain the necessary processing and storage of verbally-based material in the course of language processing and other learning activities. The combination of deficits, it appears, may have dramatic consequences on the ability to learn language.

One strength of the present study was its use of multiple standardised and validated measures associated with each of the aspects of immediate memory function under investigation, via the Working Memory Memory Test Battery for Children (WMTB-C, Pickering & Gathercole, 2001; see also, Gathercole, Pickering, Ambridge, & Wearing, 2004). Aggregation of the multiple measures permits more reliable and robust assessment of each construct than reliance on any single measure alone, as in many previous studies in the area. It is, however, worth noting that there was some degree of variability in the degree of deficits in individual measures within constructs found in the sample. In particular, only 20% of the children obtained deficit scores on the word list matching measure of verbal short-term memory, contrasting with 70% of children on the composite scores for this construct based on a total of four sub-tests from the WMTB-C. A similar reduced sensitivity of this measure to verbal short-term memory deficits was found by Gathercole et al. (2005), and seems likely to arise from the 50% chance of successful guessing on this recognition paradigm. The sample also varied in both the magnitude and consistency of their impairments on the working memory tests, with 90% of the sample obtaining scores in the deficit range on the counting recall measure, and only 30% on listening recall. The more marked impairment on the counting recall task may reflect the particularly high degree of sensitivity of both simple counting strategies and the acquisition of counting knowledge to working memory constraints, as recently argued by Geary, Hoard, Byrd-Craven, & DeSoto (2004) in a study of children with mathematical disability. Importantly, however, the group profile was not substantially distorted by inclusion of the counting recall measure in the assessment of working memory performance. The group profile was characterized by low performance across all of the complex memory tasks, a pattern that was rare in a general population of typically developing children, and a substantial majority of the children obtained deficit scores on more than one of the complex memory tasks completed.

An unexpected finding was that less than half of the SLI group showed deficits on measures of phonological awareness, in apparent contradiction to previous reports of impaired phonological awareness skills in SLI (e.g., Bishop & Adams, 1990; Catts, 1993; Stackhouse, 1997). The current study differs from earlier research in that older school age children who have been exposed to reading instruction for many years were included whereas much of the previous work has focused on preschoolers or children in their first year or two of formal school. It is notable that phonological awareness has become widely recognised over the past 10 years by the educational community in the UK as providing the foundation for literacy acquisition. The children were therefore likely to have received specific interventions targeting phonological awareness that may have successfully promoted this cognitive ability. Most pertinent to the present study, the greater severity and pervasiveness of deficits of verbal/phonological short-term memory than phonological awareness in the present sample favours the view that the cognitive skills underlying these measures are to some extent dissociable from one another (e.g., Alloway, Gathercole, Willis, et al., 2004).

A final issue addressed by this study concerned the extent to which the immediate memory deficits of children with SLI were specific to language-based tasks. Visuospatial short-term memory scores fell in the average range for the group overall, while a substantial minority of the children did score below average, these scores were appropriate for their language ages. These findings contrast markedly with the large and consistent deficits in verbal short-term memory that exceeded the magnitude of the criterial language deficits of the group. The children with SLI also exhibited working memory deficits, however all of the working memory measures included in this study were verbal in nature. Thus, it is not possible to determine if the working memory deficits exhibited by the SLI group are specific to the verbal domain, or are more generalized. This question was addressed directly in the following study presented in chapter 3 by employing working memory measures that tapped the visuospatial domain.

The children with SLI in the present study had consistent and substantial deficits in verbal short-term memory and working memory that exceeded their criterial impairments. These findings have potentially important implications for the assessment and remediation of children with SLI. Possible methods for minimizing the adverse consequences of deficits in verbal short-term memory are considered by Montgomery (2002), although as yet, effective methods for alleviating learning difficulties associated with working memory impairments have not been developed. Learning support strategies that reduce the working memory demands of learning activities (Gathercole, Lamont, & Alloway, 2005) may be an effective intervention for children with SLI. Possible strategies may include reducing the amount of material to be stored, simplifying linguistic structures, and increasing the degree of familiarity of material (Gathercole & Alloway, 2006).

Chapter 3

Visuospatial Immediate Memory in Specific Language Impairment

As reviewed in section 1.5, there has been considerable interest in the last decade in the cognitive processes that underlie Specific Language Impairment (SLI), and the results reported in chapter 2 as well as a number of other studies have implicated deficits of immediate memory (e.g., Ellis Weismer, 1996; Montgomery, 1995a, b). Many of these studies have focused on the short-term storage of phonological information (e.g., Edwards & Lahey, 1998; Gathercole & Baddeley, 1990a), while others have examined the processing load imposed by verbal information on working memory (e.g., Ellis Weismer, et al., 1999; Montgomery, 2000a, b). The purpose of the present study was to investigate the extent to which deficits in immediate memory in SLI may extend to the visuospatial domain by assessing visuospatial short-term and working memory in a group of children with SLI previously found to exhibit marked impairments in both verbal short-term and working memory (chapter 2).

Immediate memory processes have been widely researched within the context of the working memory model originally advanced by Baddeley and Hitch (1974) consisting of a central executive and two short-term memory stores (see section 1.2). Working memory is related to but distinguishable from short-term memory. The term working memory is widely used to refer to the capacity to store information while engaging in other mentally demanding activities, and is typically assessed using complex memory span paradigms that impose demands both for temporary storage and significant processing activity with selected task components varied across domains. Short-term memory, on the other hand, is assessed in tasks that impose storage demands only, without further information processing.

A number of distinct theoretical conceptualizations of working memory exist, although a common feature shared by most is the distinction between the storage-only capacities of short-term memory and the more flexible nature of working memory. Within the working memory model (Baddeley & Hitch, 1974), the storage demands of complex memory span are suggested to depend on appropriate subsystems, with processing supported principally by the central executive (Baddeley & Logie, 1999; Cocchini, et al., 2002). This view fits well with evidence that verbal and visuo-spatial complex memory tasks comprise both a common component related to general processing efficiency that is a good predictor of academic achievement (Bayliss, et al., 2003) and general intelligence (Engle, Tuholski, et al., 1999; Kane, et al., 2004), and also domain-specific components related more generally to verbal and visuo-spatial abilities (Daneman & Tardif, 1987; Jurden, 1995; Shah & Miyake, 1996). Alternative accounts of working memory incorporate both domain-specific storage and processing components (Shah & Miyake, 1996), while others place more emphasis on the use of domain-general resources that can support either processing or storage (Daneman & Carpenter, 1980; Just & Carpenter, 1992). Recent theoretically-neutral individual differences analyses of the structure of working memory favour the co-existence of a domain-general working memory resource supplemented by domain-specific storage systems (Kane et al., 2004.).

In recent years, standard methods of assessing both verbal and visuospatial aspects of immediate memory have been developed and validated. Two tests, the *Working Memory Test Battery for Children* (WMTB-C; Pickering & Gathercole,

2001) and the *Automated Working Memory Assessment* (AWMA; Alloway, Gathercole, & Pickering, 2004), provide multiple measures of domain-specific short-term and working memory standardized for children aged 4 to 11 years. Analysis of the data from the standardization studies of these tests reinforced conclusions that recall of verbal or visuospatial materials was not mediated by cross domain effects (Gathercole, Pickering, Ambridge, et al., 2004). These tests therefore allow for the systematic assessment of short-term and working memory within the verbal and visuospatial domains that is appropriate for young children.

Investigations of immediate memory function in SLI have focused almost exclusively on verbal memory paradigms (e.g., Ellis Weismer, 1996; Ellis Weismer et al., 1999; Montgomery, 1995b, 2000b). As reviewed in section, 1.4.1, evidence for a verbal short-term memory deficit in SLI comes largely from studies of nonword repetition (e.g., Bishop et al., 1996; Conti-Ramsden et al., 2001; Dollaghan & Campbell, 1998; Edwards & Lahey, 1998; Ellis Weismer et al., 2000; Gathercole & Baddeley, 1990a), although deficits have been found also on serial recall of verbal information such as digits (chapter 2; Conti-Ramsden, 2003b; Graham, 1980), and free-recall of pictured items (Kirchner & Klatzky, 1985). It has been suggested that verbal short-term memory plays a key role in new word learning by generating a brief phonological representation for transfer to long-term memory (Baddeley, Gathercole, et al., 1998), and that children with SLI may have more difficulty learning new phonological forms because their short-term memory representations are inadequate (Gathercole & Baddeley, 1990a).

Substantial deficits on verbal complex memory tasks that tap working memory have also been found in groups with SLI (Ellis Weismer et al., 1999; Montgomery, 2000a, b). In the study in chapter 2, both verbal short-term and working memory were examined in the same group of school-age children with SLI using tasks from the WMTB-C (Pickering & Gathercole, 2001). Verbal working memory was assessed in three tasks involving the simultaneous storage and processing of verbal information. Group performance was markedly impaired on these complex memory tasks, with 95% of the sample scoring in the deficit range on the composite verbal working memory measure. Verbal short-term memory was tested in conventional serial recall of digits, words, and nonwords, as well as in multisyllabic nonword repetition. Group performance was impaired also on these short-term memory tasks, with 70% of the sample showing impairments on the composite verbal short-term memory measure. Importantly, deficits in verbal short-term and working memory persisted even when scores were adjusted for individual language level. On this basis, it was suggested that limitations in immediate verbal memory may impair the abilities of individuals with SLI to maintain and integrate verbal information within working memory, and that this may underlie some of the verbal learning problems characteristic of this disorder.

An alternative view of the poor performance on verbal short-term memory and complex span tasks of children with SLI is that they arise from a limitation in general processing capacity (Ellis Weismer, 1996; Bishop, 1992; Johnston, 1994) or speed (Kail, 1994). It has been suggested that a general processing account of SLI captures the limitations demonstrated by children with SLI on a range of non-linguistic cognitive tasks (Ellis Weismer, 1996; see also, Johnston, 1994). More recently, children with SLI have been found to respond more slowly than typically developing children on a variety of linguistic and non-linguistic measures (Miller, et al., 2001). Miller et al. proposed that the generalized slowing gives rise to SLI because the operations central to language learning are particularly time-dependent.

The present study was designed to investigate the extent to which the immediate memory deficits associated with SLI are specific to the verbal modality, or represent more general impairments in either processing or storage that extend to other modalities. A few studies have yielded evidence that the memory deficit in SLI may extend to the visuospatial domain. It should be noted however that typically, these studies did not use methods of assessing visuospatial short-term and working memory that are conventionally used in this research area. Particular problems relate to opportunities for verbal recoding provided by, for example, the use of colour matching to identify locations (Hoffman & Gillam, 2004), and also by including a delay prior to responding (Doehring, 1960; Montgomery, 1993; Poppen, et al., 1969; Wyke & Asso, 1979). It should be noted that equivocal results for SLI and age-matched groups have also been reported (Bavin et al., 2005; Hick et al., 2005). Converging evidence was provided by the study outlined in chapter 2, which employed several measures of visuospatial short-term memory from the WMTB-C providing no opportunities for verbal recoding (Pickering & Gathercole, 2001). Group performance was in the average range on these tasks, and contrasted markedly with the accompanying severe and pervasive verbal memory deficits, although substantial individual variability was found.

One aim of the present study was to assess the visuospatial short-term and working memory abilities of the group of children with SLI who participated in the previous study and for whom substantial deficits of both verbal short-term and working memory were established (chapter 2). The second aim was to compare the short-term and working memory capacities of children with SLI and children with typically developing language abilities on standardized and validated measures of visuospatial immediate memory. Findings that children with SLI are unimpaired on both visuospatial short-term memory and complex span tasks would suggest that the immediate memory deficits in SLI are specific to the verbal domain. Evidence for a more general impairment to the immediate memory systems would be provided by findings of either comparable deficits on both verbal and visuospatial memory tasks in the SLI group, or deficits in visuospatial immediate memory of the SLI group relative to the typically developing groups.

3.1: Method

3.1.1: Participants

Forty-five children participated in three groups in the present study, 15 children with SLI, 15 chronological age-matched controls (age-match), and 15 language age-matched controls (language-match). Each group comprised 9 males and 6 females. The mean ages of the groups were as follows: SLI, 9 years; 8 months (*SD*=1.66, *R*=7;3-12;5), age-match, 9;8 (*SD*=1.66, *R*=7;0-12;5), and language-match, 6;0 (*SD*=1.48, *R*=4;4-10;4). All participants achieved a standard score of 85 or greater on a test of nonverbal reasoning (*Raven's Colored Matrices*; Raven, Court & Raven, 1986), and a test of articulation

(*Goldman Fristoe Test of Articulation-2*; Goldman & Fristoe, 2000). All of the children were native English speakers. None of the children were diagnosed with ADD/ADHD, or Autism Spectrum Disorder.

SLI Group. The 15 children in the SLI group participated in the previous study (chapter 2). The children met identification criteria for SLI consistent with that described by Records and Tomblin (1994). They performed at least 1.25 *SD* below the mean on two of the four language measures including one receptive measure. [Note the minor changes in the inclusion criterion relative to the study in chapter 2 of a score of at least 1.25 rather than 1.0 *SD* below the mean on one receptive measure, and a score above 84 rather than 79 on the GFTA-2.] The receptive measures were the *British Picture Vocabulary Scales, 2nd edition* (BPVS-II, Dunn, et al., 1997) and the *Test for Reception of Grammar* (TROG, Bishop, 1982). The expressive measures were the *Expressive Vocabulary Test* (EVT, Williams, 1997), and the *Recalling Sentences* subtest of *Clinical Evaluation of Language Fundamentals – UK 3* (CELF-UK3, Semel, et al., 1995). None of the children received a score greater than 131 on the *Children's Communication Checklist* (Bishop, 1998), indicating that none had a marked pragmatic impairment.

Table 3.1

Descriptive statistics for standardized criterion measures for all groups, and verbal short-term and working memory for SLI group

Measure	Score	Participant Group					
		SLI		age-match		language-match	
		M	*SD*	*M*	*SD*	*M*	*SD*
Raven's	RS	25.80_a	4.65	29.47_a	3.20	20.13_b	3.83
Matrices	SS	103.47	9.76	112.73	11.01	109.07	8.26
GFTA-2	RS	5.33_a	2.35	0.47_b	1.55	5.47_a	4.90
	SS	92.47	3.20	103.27	5.39	104.20	5.94
BPVS-II	RS	66.40_a	12.36	101.07_b	16.48	65.73_a	14.07
	SS	77.73	9.52	105.27	13.09	105.47	10.38
TROG	RS	11.33_a	2.77	17.73_b	1.39	12.67_a	2.72
	SS	76.33	7.80	107.80	10.14	101.47	10.55
EVT	RS	69.07_a	10.76	90.73_b	17.75	60.33_a	9.32
	SS	79.73	11.94	99.87	14.38	101.07	11.75
Recalling	RS	16.73_a	4.40	42.87_b	12.00	20.20_a	7.77
Sentences	ScS	3.20	0.56	8.87	3.18	6.47	2.56
Verbal STM	SS	80.15	7.99	n/a	n/a	n/a	n/a
VSSP STM	SS	90.76	12.47	n/a	n/a	n/a	n/a
Verbal WM	SS	80.33	5.25	n/a	n/a	n/a	n/a

Note. Raven's Matrices = Raven's Colored Progressive Matrices; GFTA-2 = Goldman Fristoe Test of Articulation – 2; BPVS-II = British Picture Vocabulary Scales, 2nd ed.; TROG = Test for Reception of Grammar; EVT = Expressive

Table continues

Vocabulary Test; RS = raw score; SS = standard score (*M*=100, *SD*=15); ScS = scaled score (*M*=10, *SD*=3); n/a = not available. For raw scores, means in the same row that do not share subscripts differ at $p<.01$ in the Tukey HSD comparison.

Summary statistics for the standardized criterion measures for the SLI group are presented in Table 3.1. Group means for the BPVS-II, TROG, and EVT were approximately 1.5 *SD* below the standardized mean, and more than 2 *SD* below the mean for Recalling Sentences. The proportion of children who scored below 81 on the BPVS-II was 0.73, 0.67 on the TROG, 0.60 on the EVT, and the entire group on the Recalling Sentences subtest. Individual language profiles conformed closely to the group pattern with ten participants scoring more than 1.25 *SD* below the mean on three or four of the language measures. The mean standard composite scores of the tests tapping verbal short-term memory, verbal working memory, and visuospatial short-term memory administered in the study described in chapter 2 are shown in Table 3.1 for the present SLI group. Group means were approximately 1.25 *SD* below the standardized mean for verbal short-term memory and verbal working memory whereas performance on the visuospatial short-term memory measures was in the average range.

Control Participants. The children participating in the control groups were recruited over a one-month period from a school with a similar lower-middle class profile to the schools attended by the SLI group two months after recruitment of the SLI group. None of the children had any history of speech, language or hearing problems, or any type of exceptional educational needs, and all had passed a routine hearing screening according to school records. All of the children scored within 1 *SD* of the mean for their age on the BPVS-II, TROG, and EVT. Four children, two in each of the age-match and language-match groups scored below a scaled score of 7 on the Recalling Sentences subtest. In order to ensure that selection decisions were based on language rather than memory skills as described in section 2.1.1, all of these participants completed and passed the *Word Structure* expressive grammatical subtest of the CELF-UK3, indicating age appropriate expressive language skills. The age-match group were matched to the SLI group on sex and age (mean age difference in months=3.97, *SD*=2.58). Children in the language-match group were matched to the SLI group on sex and BPVS-II raw score (mean difference in raw score=2.4, *SD*=2.16). Maternal education was measured on a 6-point scale: 0 – no qualifications, 1 – 1-3 'O' levels, 2 – 4-9 'O' levels, 3 – 1 or more 'A' levels, 4 – vocational qualification, 5 – higher degree. Group means on this scale of 1.77 (*SD*=1.89), 2.27 (*SD*=1.67), and 2.60 (*SD*=2.10) for the SLI, age-match, and language-match groups, respectively, did not differ significantly in a one-way ANOVA (p>.05, all cases).

Table 3.1 presents summary statistics for the standardized criterion measures for both control groups as well as the SLI group. Group differences in raw scores for each measure were assessed using one-way ANOVAs. There was a significant main effect of group on all measures at p<.001. The age-match group had significantly higher raw scores than the SLI group on all measures at p<.001 except the Raven score (p=.044), whereas the SLI and language-match groups did not differ significantly on raw score on any of the screening measures (p>.05) except the Raven score (p=.001).

3.1.2: Procedure

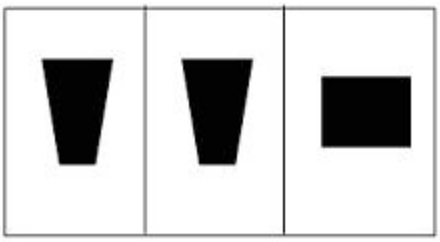
Each child was tested individually in a quiet room in school in three half hour sessions. The screening measures described above were administered in two sessions at the time of recruitment. Once recruitment of all participant groups was complete and within six months, four visuospatial short-term memory tasks and two nonword repetition measures not reported here (see chapter 5) were administered in a single half hour session. The four visuospatial measures were designed to tap visuospatial short-term memory (dot matrix) and visuospatial complex working memory (odd one out, Mr. X, spatial span).

The visuospatial tasks were subtests of the PC-based *Automated Working Memory Assessment* (AWMA; Alloway et al., 2004). The children responded by pointing to their choice, and the presenter clicked on the choice to advance the program. The tasks were ordered from simple to most complex because skills learned in previous tasks could then be applied to new tasks; as such the task order was fixed at *dot matrix, odd one out, Mr. X,* and *spatial span*. Results of test-retest reliability measures completed during the standardization of the AWMA for each subtest are reported below with the description of each task.

Visuospatial short-term memory. In the *dot matrix* task, a sequence of red dots is presented on a 4 X 5 grid, and the child is required to point to the positions of each dot that had appeared in the sequence in the same order. Each dot appeared for 2 seconds. Following a practice session, a maximum of six trials is presented at each length. The number of dots presented increases by one if the child recalls four sequences at that length correctly. If the first four trials are correct, the child is credited with correct repetition of all six trials and the next length commences. Testing begins with a single dot, and increases by one additional dot until three trials at that length are repeated incorrectly to a maximum of nine dots. The task score is equivalent to the number of trials repeated correctly and any credited trials. Test-retest reliability for this task was 0.83.

Visuospatial working memory. In the *odd one out task*, the child is presented with a horizontal row of three boxes in which three complex shapes are presented (see Figure 3.1). The child points to the shape that does not match the others, and remembers its location. At the end of the trial, a blank set of three boxes appears on the screen. The child points to the boxes in which the odd shapes had appeared in the correct order. Test trials begin with one set of boxes, and increase by one set of boxes according to the span procedure outlined above to a maximum of seven boxes. The boxes always appear centred horizontally on the screen, but at different positions along the vertical axis in order to eliminate visual traces. Test-retest reliability for this task was 0.81.

Figure 3.1. Template used in the odd one out task



In the *Mr. X* task, the child sees two identical Mr. X figures except that the Mr. X on the left is wearing a yellow hat, and the Mr. X on the right, a blue hat (Figure 3.2a). Each Mr. X has a ball in one hand and the child is asked to judge if the Mr. X with the blue hat has his ball in the same hand as the Mr. X with the yellow hat, and to remember the location of the ball of the Mr. X with the blue hat. Mr. X with the blue hat rotates to eight possible positions in a circle. Once the Mr. X figures are removed from the screen, a circle of eight dots reflecting the possible positions to which Mr. X's ball may have been pointing as a result of his circular rotation are displayed, and the child points to the corresponding dot, or dots in the correct order (Figure 3.2b). Testing starts with one set of Mr. X figures, and increases by one set according to the span procedure outlined above to a maximum of seven Mr. X pairs. Test-retest reliability for this task was 0.77.

Figure 3.2a. Template used in the Mr. X task. The Mr. X on the right rotates to eight possible positions. The child judges if the Mr. X on the right has the ball in the same hand as the Mr. X on the left.

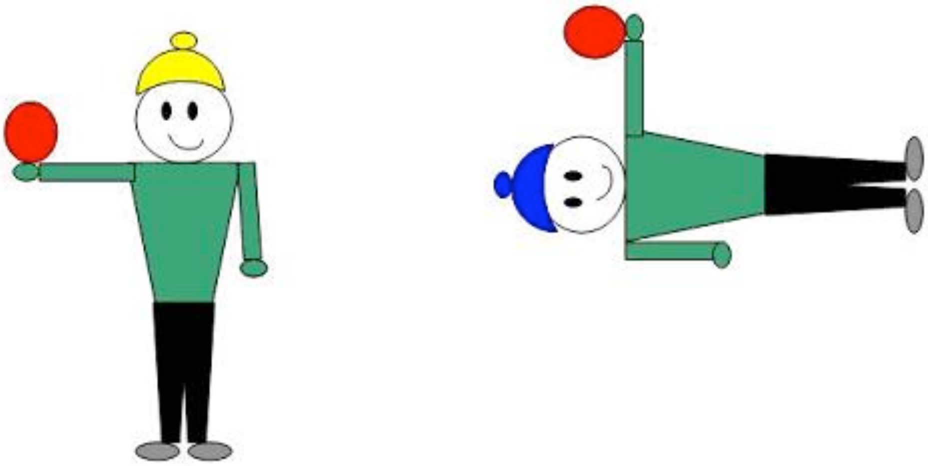
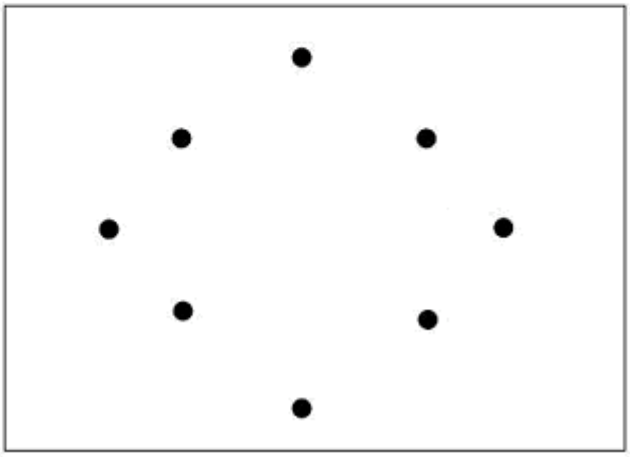
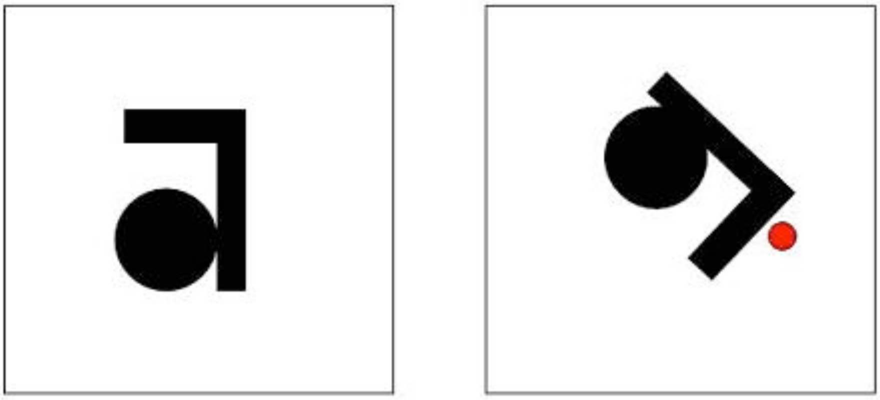


Figure 3.2b. Mr. X response form. The child points to the dot(s) indicating the position to which Mr. X was rotated in sequence.



In the *spatial span* task, the child is presented with two identical shapes (except that the one on the right has a red dot above it) and is asked to judge if the shape with the dot is the normal or mirror image of the one next to it, and to remember the location of the dot (Figure 3.3). The shape with the dot may be rotated to eight possible positions in a circle as in the Mr. X task. Once the shapes are removed from the screen, the circle of eight dots corresponding to the eight possible positions of shape rotation are presented, and the child points to the corresponding dot(s) in sequence. Testing starts with one set of shapes, and increases by one set according to the span procedure outlined above to a maximum of seven shape sets. Test-retest reliability for this task was 0.82.

Figure 3.3. Template for the spatial span task.



For all of the visuospatial tasks, several practice trials were administered. The presenter had the option of repeating the practice trials in order to ensure that the child understood the task before proceeding. In all cases, the children accurately completed the practice trials without prompting from the presenter prior to beginning the task and indicated that they understood the task. However, it is possible that some of the children failed to fully comprehend the more difficult aspects of the complex tasks. If such a problem existed, one way in which it may be reflected in the data is in a failure to complete the first level of the task. Successful completion of level one of the tasks (i.e., a minimum score of 4) would indicate that the child has understood the task requirements, whereas a score below this level may indicate that the child failed to comprehend the task requirements. Inspection of the raw data indicated that all of the children in the SLI and age-match groups scored at this level or above, while two children in the language-match group scored below this level on the Mr. X task, and three on the spatial span task. One child in the language-match group scored below this level on both the Mr. X and spatial span tasks. Thus, basal level performance was established for all of the SLI and age-match groups on all of the tasks. For the language-match group, basal level performance was established for the entire group on the dot matrix and odd-one-out tasks, and for over 70% on the remaining tasks (Mr. X: 80%; spatial span: 73%). All data was considered valid for analysis, however, as an added control, the analyses were computed with individuals in the language-match group who did not achieve a minimum score of 4 removed from the sample, and the patterns between the SLI group and the other two groups were unchanged.

Statistical Analysis. Groups were compared on all four visuospatial immediate memory measures in a multivariate analysis of variance (MANOVA). This analysis provided an assessment of group differences on each individual measure, as well as all of the measures combined. Also, a multivariate analysis of covariance (MANCOVA) was performed on the data with measures of language (BPVS-II) and general nonverbal cognitive (Raven raw score) abilities entered as covariates in order to assess group differences once scores were adjusted for differences in language and cognitive level.

3.2: Results

Table 3.2

Descriptive statistics for visuospatial storage and processing measures

Task	Statistic	Participant Group		
		SLI	age-match	language-match
VSSP STM				
Dot Matrix	*M*	19.20_a	21.67_a	14.93_b
	SD	3.97	5.21	4.42
	95% *CI*	16.82 to 21.58	19.29 to 24.05	12.56 to17.31
	n<1 *SD*	3	2	n/a
VSSP WM				
Odd One Out	*M*	15.80	17.33_a	13.60_b
	SD	3.84	4.10	2.77
	95% *CI*	13.92 to 17.68	15.45 to 19.22	11.72 to 15.48
	n<1 *SD*	2	1	n/a
Mr. X	*M*	8.33	10.80_a	5.80_b
	SD	2.47	4.52	2.81
	95% *CI*	6.57 to 10.01	9.04 to 12.57	4.04 to 7.57
	n<*1* SD	0	1	n/a
Spatial Span	*M*	11.80_a	11.73_a	5.13_b
	SD	3.32	3.81	3.44
	95% *CI*	9.96 to 13.64	9.89 to13.57	3.29 to 6.97
	n<*1* SD	0	0	n/a

Note. VSSP = visuospatial; STM = short-term memory; WM = working memory; 95% *CI* = confidence interval around the mean; n<1 *SD* = number in

Table continues

the group whose raw scores fell below the cut off score; n/a = not applicable. Means in the same row that do not share subscripts differ at $p<.05$ in the Tukey HSD comparison. Means without subscripts do not differ from other means in the same row ($p>.05$).

Table 3.2 provides descriptive statistics for the four visuospatial tasks for the SLI group, and the age-match and language-match controls. The performance of the SLI group was comparable to that of the age-match groups on all measures, and higher than that of the language-match group. Results of the MANOVA investigating group differences on the four measures of visuospatial memory revealed a significant group effect, Hotelling's $T(8,80)=4.442$, $p<.001$, $\eta_p^2=.36$. All of the univariate group comparisons were significant with small to moderate effect sizes: dot matrix, $F(2,42)=8.358$, $p<.001$, $\eta_p^2=0.29$, odd-one-out, $F(2,42)=4.039$, $p<.05$, $\eta_p^2=0.16$, Mr. X, $F(2,42)=8.167$, $p<.001$, $\eta_p^2=.28$, and spatial span, $F(2,42)=17.667$, $p<.001$, $\eta_p^2=.46$. Planned *post hoc* comparisons using the Tukey HSD test indicated that the mean scores for the SLI group were not significantly different than their age-match controls on any of the measures ($p>.05$, each case), and were significantly higher than the language-match group on the dot matrix ($p<.05$) and spatial span tasks ($p<.001$). The age-match group scores were significantly higher than the language-match group scores on the dot matrix and spatial span measures at $p<.001$, and on the odd-one-out and Mr. X measures at $p<.05$.

Confidence intervals around the sample mean for each participant group and measure are provided in Table 3.2 (95% *CI*), and provide a range estimate for the population mean. Each interval was inspected to determine whether the mean of the other participant groups fell within the interval thereby providing an additional indication that the groups do not differ, or outside of the interval indicating the groups may differ. Consider first the confidence intervals around the means for the SLI and age-match groups. The mean of the SLI and age-match groups fell within the range of the 95% *CI* of the mean of the other group for both the odd-one-out and spatial span tasks, and within a 0.09 margin of the interval for the dot matrix task. For the Mr. X task, the SLI and age-match group means fell outside of the other group's 95% *CI* of the mean. In comparison with the language-match group, the SLI and age-match group means fell above the range of the 95% *CI* of the mean of the language-match group for all tasks. These results provide further evidence for the equivalence in performance of the SLI and age-match group, with the possible exception of the Mr. X task.

In order to explore the possibility that the Mr. X task taps a different range of cognitive processes, including possibly verbal abilities, a correlation matrix was computed between all of the memory measures and the full range of screening tests for data from participants from all three groups (*n*=45). These screening tests provided indices of several related cognitive processes including, nonverbal cognitive ability (Raven's Matrices raw score), articulation (GFTA-2 raw score), and language development (BPVS-II, TROG, EVT, recalling sentences). As all of the skills and capacities tapped by these measures are known to increase over the age range of the children involved in this study (4-12 years), high correlations reflecting the developmental trajectory were expected in all cases. The partial correlations, calculated while controlling for age, therefore, provide more meaningful information about the patterns of association. Zero and first order correlation coefficients are summarized in Table 3.3. Only the Mr. X measure was uniquely and significantly correlated with any of the other indices, including the nonverbal cognitive measure, Raven's raw score (partial r=0.50, p<.01), and the language measures (partial r ranges from 0.37 to 0.60, p<.05 all cases).

Table 3.3

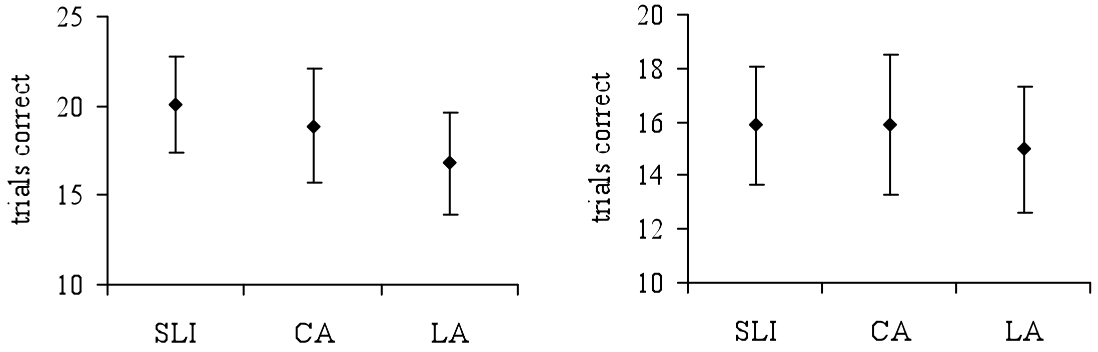
Correlations, and (partial correlations controlling for age), between the experimental tasks and screening measure raw scores

	Dot matrix	Odd-one-out	Mr. X	Spatial Span
Ravens	.55**	.47**	.66**	.57**
	(.22)	(.25)	(.50**)	(.10)
GFTA-2	-.41**	-.37*	-.42**	-.53**
	(-.17)	(-.20)	(-.23)	(-.30)
BPVS-II	.52**	.38*	.61**	.44**
	(.28)	(.18)	(.46**)	(.08)
TROG	.49**	.46**	.51**	.37*
	(.32)	(.33)	(.37*)	(.09)
EVT	.43**	.42**	.71**	.56**
	(.11)	(.22)	(.60**)	(.22)
Recalling Sentences	.37*	.29	.50**	.40**
	(.21)	(.15)	(.39**)	.22

Note. Ravens = Raven's Colored Progressive Matrices; GFTA-2 = Goldman Fristoe Test of Articulation – 2; BPVS-II = British Picture Vocabulary Scales, 2nd ed.; TROG = Test for Reception of Grammar; EVT = Expressive Vocabulary Test. **p*<.05; ***p*<.01

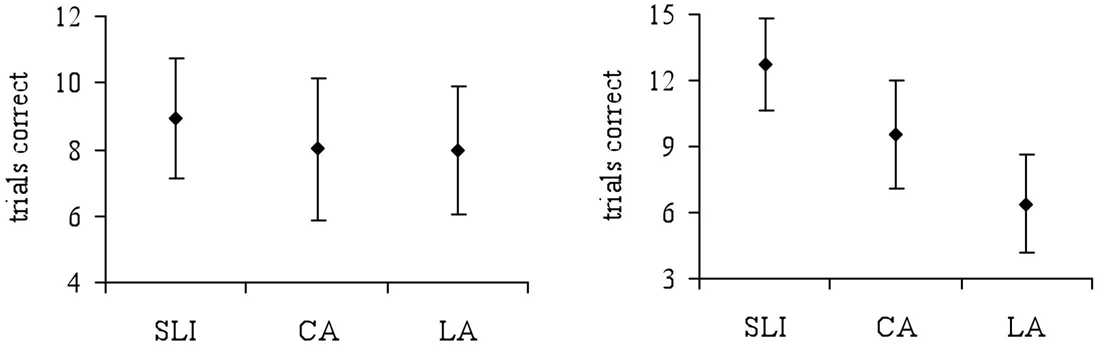
The close links between scores on the Mr. X task and measures of both verbal and nonverbal ability suggest that this task draws upon a range of general cognitive resources in addition to working memory skills. In order to control for individual differences in verbal and nonverbal ability, group differences on the four visuospatial measures were retested in a MANCOVA with Raven's raw score and BPVS-II raw score entered as covariates. Results revealed a significant group effect, Hotelling's $T(8,72)=2.210$, $p<.05$, $\eta_p^2=0.12$. One of the univariate group comparisons was significant, spatial span, $F(2,40)=8.893$, $p<.001$, $\eta_p^2=0.31$. All of the remaining univariate comparisons were not significant and effect sizes did not go above 0.07. Bonferroni-adjusted *post hoc* pairwise comparisons indicated that the SLI group achieved a significantly higher score than the language-match group ($p<.001$). The remaining pairwise comparisons were not significant ($p>.05$, all cases). Figure 3.4 displays the adjusted means and 95% confidence intervals for all tasks and each participant group. There was a large degree of overlap in the confidence intervals for all groups on each task, except for the spatial span task for which the mean of the SLI group fell above the range of the 95% *CI* for both of the typically developing groups. In addition, the means of the SLI and language-match groups fell outside of the other group's interval range on the dot matrix task, with the mean of the SLI group falling above that of the language-match group. These results indicate that once scores were adjusted for verbal and nonverbal ability, the performance of the SLI group was entirely age-appropriate, and better than the younger language-match group on the spatial span task.

Figure 3.4. Mean trials correct (and 95% *CI*) adjusted for nonverbal cognitive abilities and language skill for the SLI, age-match (CA), and language-match (LA) groups for each visuospatial memory task.



a) Dot matrix

b) Odd-One-Out



c) Mr. X

d) Spatial Span

The analyses reported so far focus on group differences in visuospatial immediate memory. A further issue of interest was the degree to which individuals exhibited consistently low performance on the visuospatial memory tasks, and whether children in the SLI group were more likely to exhibit such a pattern. Raw scores were inspected relative to a cut off score in order to establish whether individuals performed in the deficit range on any of the measures. As the age-match and SLI groups did not differ on any of the measures, the cut off score was defined as the overall mean for the grouped scores (n=30) minus 1 *SD* for each measure. This cut off point corresponds to the 16th centile on a normal distribution and to an effect size of 1.0, conventionally considered to be large (Cohen, 1988). The number of participants scoring below the cut off for the SLI and age-match groups on each measure is shown in Table 3.2 (n<1 *SD*). Four members of the SLI group scored below the cut off on one visuospatial memory measure, and one member of the SLI group scored in this range on two measures. Similarly, three members of the age-match group scored below the cut off on one measure, and one on two measures. Visuospatial memory deficits in individual children were therefore not markedly more frequent in the SLI group relative to control children. In contrast, 73% of the SLI group obtained a standard score of less than 86 on both the verbal short-term and working memory composite scores of the WMTB-C (Pickering & Gathercole, 2001).

One final aspect of the results to consider is the degree of association between the visuospatial memory measures, and the most closely related screening measure, the Coloured Progressive Matrices (Raven et al., 1982). The matrices test taps visuospatial abilities, however it is distinguished from the experimental measures in that there is no additional memory load. In contrast, the visuospatial memory measures require the processing and storage of relatively simple visuospatial tasks. Age-appropriate performance on the matrices test was one of the participant selection criteria for this study, and it is important that this criterion did not influence the variability of performance in the participant pool. One way to assess this is through the correlations provided in Table 3.3. The absence of significant partial correlations between the Raven's raw score and three of the visuospatial measures (dot matrix: partial *r*=0.22; odd-one-out: partial *r*=0.25; spatial span: partial r=0.10, *p*>.05, all cases) indicates performance on the experimental tasks was not highly associated with performance on the matrices task, and rules out the possibility that the criterion set for the matrices measure restricted participant performance on the experimental tasks.

3.3: Discussion

This study provided no evidence that children with SLI have deficits in visuospatial aspects of either short-term memory or working memory, with the children performing at comparable levels to age-matched control children in both cases, and performing more highly on one visuospatial working memory measure than the language control group. These findings contrast markedly with the large and consistent impairments of verbal short-term and working memory exhibited by the children in the SLI group (Table 3.1, see also Chapter 2).

The present results suggest that the immediate memory deficits in SLI primarily involve the verbal domain. The findings are readily accommodated by domain-specific hypotheses regarding the impaired memory processes underlying SLI, such as the verbal short-term memory deficit proposed by Gathercole and Baddeley (1990) and the co-existence of verbal short-term and working memory deficits proposed in chapter 2. In chapter 2, it was suggested that the poor verbal short-term and working memory function of children with

SLI compromises their abilities to learn the phonological forms of language, and constrains language learning more generally.

The data represent a substantial challenge to proposals that SLI arises from a deficit in general processing capacity (Johnston, 1994; Ellis Weismer, 1996). The marked impairments on verbal short-term and verbal complex memory tasks in our previous study and age-appropriate performance on visuospatial working memory tasks in the same individuals with SLI appear to rule out explanations in terms of domain-general mechanisms. This conclusion is reinforced by our earlier findings that the verbal memory deficits of the present SLI group persisted even when scores were adjusted for language ability (chapter 2). While the present study was not designed to evaluate the generalized slowing hypothesis (Kail, 1994), it is not necessarily challenged by the current findings. According to this account, the slow processing in SLI would be expected to have a particularly strong impact on tasks requiring rapid and complex processing such as language, but may have less of an impact on other kinds of activities such as the present experimental tasks.

The contrasting performance of the children with SLI on tasks of verbal working memory and visuospatial working memory adds to the growing evidence that working memory may be fractionated into distinct verbal and visuospatial components (e.g., Daneman & Tardif, 1987; Shah & Miyake, 1996). Kane et al. (2004) argued that these studies have typically relied on cognitively-restricted, high-ability participant samples that may underestimate the contribution of general ability, and have often relied on a single measure each of verbal and visuospatial working memory. Neither of the criticisms applies in the present case. The children in the present study had wide-ranging general ability levels (Raven Matrices standard scores ranging from 93-125), and three measures were used to assess both visuospatial and verbal working memory skills. The SLI group performed at similar levels to typically developing children of the same age on visuospatial working memory tasks even when scores were adjusted for differences in language and general ability, but had marked deficits in verbal working memory. The strength in the visuospatial skills of the SLI group is suggested also by the observation that their scores improved with practice to a greater extent than the other two typically developing groups as reflected by their better performance on the last and most difficult task administered, spatial span, relative to the other two groups. The present findings therefore provide substantial evidence for a specific verbal working memory deficit in SLI, accompanied by preserved visuospatial working memory function.

A selective impairment of verbal short-term and working memory in SLI is also consistent with clinical and experimental evidence indicating the domain specificity of the disorder and related disorders. Clinically, SLI is characterized by a marked delay in language acquisition and impairment of verbal functioning relative to other aspects of development. In addition, children with SLI perform as accurately as typically developing children on visuospatial perceptual tasks, but respond more slowly (e.g., Johnston, 1982, Johnston & Ellis Weismer, 1983, Kiernan, et al., 1997). A similar selective deficit of verbal but not visuospatial working memory has been reported for children with another type of language deficit, poor reading comprehension (Nation, Adams, Bowyer-Crane & Snowling, 1999). Consistent with the present findings also are previous reports that children with SLI perform similarly to age-matched peers on visuospatial recall tasks when tested immediately rather than after a delay (e.g., Bavin et al., 2005; Hick et al., 2005; Doehring, 1960; Poppen et al., 1969; Wyke & Asso, 1979). Although a small number of studies have demonstrated visuospatial memory deficits in SLI groups (Hoffman & Gillam, 2004; Montgomery, 1993), it should be noted that the present study represents the first to use standardized and validated measures to assess visuospatial working memory in SLI, which are not directly comparable to the methods employed in previous studies.

The present results point to a specific area of preserved functioning in SLI. Nevertheless, one alternative account of these findings must be considered. The complex memory paradigms employed in this and the study in chapter 2 represent the ends of a continuum from wholly verbal tasks to wholly visuospatial tasks. It may be assumed that for children with a language learning impairment such as SLI the requirement to both store and process verbal information would represent the most difficult complex memory task (chapter 2), and to both store and process visuospatial information the least difficult (present study). It is possible that a general processing deficit exists in SLI, but does not always lead to impaired performance. For example, adequate performance levels may be maintained in a complex memory task even in cases of slower processing if the storage portion is not taxing. Consistent with this notion are the accounts of SLI as a deficit in processing speed (Kail, 1994) or capacity (e.g., Bishop, 1992; Johnston, 1994), which assume a disproportionate impact on the linguistic domain due either to the more time sensitive nature of verbal information (Miller et al., 2001) or the number of processing components inherent in linguistic tasks (e.g., Leonard, 1989; Leonard et al., 1991). Further research aimed at systematically investigating the nature of storage and processing deficits in SLI was undertaken in the following study presented in chapter 4.

Chapter 4

Specifying Storage and Processing Deficits in SLI

Recent investigations of the cognitive processes that underlie Specific Language Impairment (SLI) have led to proposals that deficits exist either in the abilities to process information, to store information, or both. Much of the relevant evidence is provided by complex memory paradigms in which participants engage in some form of processing activity such as reading sentences or calculating numerical operations, and simultaneously maintain certain aspects of this processing for subsequent recall. As has been found in the present thesis, children with SLI show marked deficits when the processing and storage demands of such tasks are verbal in nature, (e.g., chapter 2; Ellis et al., 1999; Hoffman & Gillam, 2004; Marton & Schwartz, 2003; Montgomery, 2000a, b), but perform appropriately for their age when the information is confined to the visuospatial domain (chapter 3; Bavin, et al, 2005). To date, however, there has been no evaluation of whether the deficit arises from impairments in verbal storage or verbal processing, or in the conjunction of the two. The aim of the present study was to provide a systematic investigation of the precise source of the verbal working memory impairment in SLI, by measuring each of the potential factors separately and in combination, across the verbal and visuospatial domains.

The evidence cited above indicates that children with SLI are disproportionately impaired in their ability to simultaneously process and store information in the verbal domain. One key issue is whether the deficit arises from a particular difficulty handling verbal information *per se*, or reflects more fundamental impairments in general processing abilities. The methods adopted in the present study address this question directly by evaluating performance on storage and processing tasks tapping different domains while maintaining common key features for comparison.

The short-term storage abilities of children with SLI have been investigated using both verbal and visuospatial versions of immediate recall tasks. As reviewed in section 1.4.1, much of the support for a verbal storage deficit in SLI comes from studies of nonword repetition, the immediate recall of novel phonological forms (e.g., chapters 5 and 6; Dollaghan & Campbell, 1998; Edwards & Lahey, 1998; Gathercole & Baddeley, 1990a). In the study reported in chapter 2, the children with SLI also performed more poorly than their typically developing peers on conventional measures of verbal short-term memory such as the serial recall of digits, words, and nonwords (see also, Conti-Ramsden, 2003b; Kirchner & Klatzky, 1985). Age-appropriate performance, on the other hand, was found for the SLI group on visuospatial storage tasks that required immediate recall of spatial position or sequence of a stimulus (chapter 2 and 3).

Children with SLI have also been found to be impaired on complex memory tasks involving both storage and processing of verbal information such as listening span requiring meaning-based judgements about a sentence while remembering the last word, and counting span requiring the counting of dots while remembering the count tallies (e.g., chapter 2; Ellis Weismer et al., 1999). As reviewed in section 1.4.3, there is some evidence that the very low levels of performance in children with SLI on such tasks cannot be explained by deficits in verbal short-term storage alone. In a recent study by Marton and Schwartz

(2003), children with SLI, and same age peers, completed tasks involving either nonword repetition in isolation (storage), or processing a syntactically simple or complex sentence and repeating the sentence-final nonword (complex memory). While impaired in the isolated nonword repetition task as expected, the SLI group showed further decrements relative to the control group in nonword repetition with each increase in syntactic complexity. Findings of the study reported in chapter 2 are consistent with this notion: SLI deficits in verbal complex memory tasks were found to be considerably greater in magnitude than in verbal storage tasks. On analogous visuospatial complex memory tasks such as those reported in chapter 3, on the other hand, children with SLI and same-age peers perform similarly (see also, Bavin et al., 2005). Taken together, these findings suggest that SLI deficits exist in both storage and processing of verbal information.

However, not all of the reported deficits exhibited by children with SLI are limited to the verbal domain. Results of several studies reviewed in section 1.5.2 and 1.5.3 indicate that children with SLI are slow to process both verbal and nonverbal information. Tallal and colleagues (e.g., Tallal & Piercy, 1973a, b; Tallal et al., 1981) have presented a series of influential studies reporting that children with SLI have difficulty processing rapidly changing signals, whether verbal or nonverbal in nature. It is argued that such a deficit will have a particularly marked impact on the perceptual analysis of speech as a consequence of the rapid transitional information present in consonants in particular (Tallal & Piercy, 1975). Children with SLI have also been found to have slower reaction times both in verbal tasks such as picture naming and grammaticality judgments (e.g., Lahey & Edwards, 1996; Miller, et al., 2001;

Montgomery, 2000a, b; Montgomery & Leonard, 1998; Stark & Montgomery, 1995; Wulfeck, et al., 2004), and in nonverbal tasks such as mental rotation and visual search (Johnston & Ellis Weismer, 1983; Miller et al., 2001; Schul, et al., 2004). According to the ‘generalized slowing hypothesis’ (Kail, 1994), the selective impact of putative problems in processing speed on language learning may arise because the operations central to language – such as the parsing and extraction of linguistically relevant details in the speech stream – are more time-dependent than are operations pertaining to other areas of cognitive functioning (Miller et al., 2001).

Performance decrements in SLI typically occur under conditions of greatest information processing demands, which has led to the proposal that limitations in general processing capacity may underlie the disorder (Bishop, 1992; Ellis Weismer, 1996; Kamhi, et al., 1985; Johnston, 1991, 1994). As reviewed in section 1.5.2, children with SLI perform more poorly than typically developing children when processing load is increased by, for example, increasing rate of presentation of novel words to be learned (e.g., Ellis Weismer & Hesketh, 1993; 1996; O’Hara & Johnston, 1997), or increasing the number of relevant pieces of information required to formulate a message or infer an answer (e.g., Johnston, et al., 1988; Johnston & Smith, 1989). Such accounts assume that the cognitive system in individuals with SLI adequately handle the processing of individual pieces of information, but is less efficient in performing operations involving several pieces of information simultaneously (Bishop, 1992). Language learning may be particularly vulnerable to such a deficit because of the sheer number of operations required to learn complex skills such as grammatical morphology (Leonard, 1989; Leonard, et al., 1997).

The working memory model reviewed in detail in chapter 1 (Baddeley, 1996, 2000; Baddeley & Hitch, 1974; Baddeley & Logie, 1999) provides a useful theoretical framework for conceptualizing possible storage and processing deficits. According to this model, the processing portions of complex memory tasks are believed to tap the flexible resources of the central executive and the storage requirements to impose a load on the respective domain storage systems – either the phonological loop or visuospatial sketchpad (Baddeley & Logie, 1999). Other working memory accounts place more emphasis on the use of domain-general resources that can support either processing or storage (Cowan, 1999; Daneman & Carpenter, 1980; Just & Carpenter, 1992).

As reviewed in section 1.2, several lines of research guided by the Baddeley and Hitch (1974) working memory model have been aimed at exploring the domain-specificity of storage and processing resources. While the distinction between verbal and visuospatial short-term storage systems is widely accepted (e.g., Fletcher & Henson, 2001; Logie, 1995; Pickering, et al., 1998), the nature of processing resources remains a matter of debate. As predicted by the working memory model, some findings have established a common processing efficiency factor underlying both verbal and visuospatial complex memory tasks (Bayliss, et al., 2003; Engle, Tuholski, et al., 1999; Kane, et al., 2004). Other research, however, indicates that processing resources may be fractionated into distinct verbal and visuospatial components (Jenkins, Myerson, Joerding, & Hale, 2000; Lawrence, Myerson, & Hale, 1998; Ninomiya, Ichimiya, Chen, Onitsuka, Kuwabara, et al., 1997). Consistent with this latter evidence, the findings that SLI impairments were observed in chapters 2 and 3 for complex memory tasks tapping verbal (see also, Ellis Weismer, et al., 1999) but not visuospatial domains (see also, Bavin et al., 2005) suggest a domain-specific processing deficit. One problem, however, is that these and other relevant studies to date have employed complex memory tasks that involve processing and storage activities tapping the same informational domains as one another, either verbal or viusospatial. It is possible that these findings do arise as a result of a general processing deficit in SLI: While disadvantaged on the processing component of both verbal and visuospatial complex memory tasks, the performance of the SLI group may be impaired only when the storage portion additionally taps their poor verbal but not preserved visuospatial storage capacities.

The purpose of the present study was to identify the role played by possible impairments in storage and processing underlying the substantial SLI deficits found for complex memory tasks. Performance of the SLI group was compared to that of two typically developing groups of children, one group of the same age, and a younger group with similar language abilities. The inclusion of a group matched for language level provides a means of controlling for the effect of current language status on task performance. Findings of deficits in children with SLI relative to a language control group may identify areas of deficit disproportionate to linguistic skill, and as such are extremely valuable in providing clues as to the aetiology of the disorder.

The present study employed the paradigm designed by Bayliss et al. (2003) that included a set of complex memory tasks incorporating all possible combinations of verbal and visuospatial storage and processing. Independent measures of verbal and visuospatial processing efficiency and storage capacity were also taken. In their studies with children and adults, Bayliss et al. found that the ability to perform the processing component of the complex span tasks was domain free, whereas the storage component clearly drew on resources specific to the storage domain involved. These findings are consistent with predictions based on the multiple resources of the Baddeley and Hitch (1974) working memory model with a domain-general processing component corresponding to the central executive, and domain-specific storage factors reflecting the phonological loop and visuospatial sketchpad. Residual variance in the complex memory tasks suggested to reflect the ability to coordinate storage and processing predicted academic achievement in the Bayliss et al. study as well.

The present study used the methods developed by Bayliss et al. (2003) to investigate the detailed nature of storage and processing deficits in SLI. If a short-term storage deficit specific to the verbal domain limits performance in SLI (e.g., Gathercole & Baddeley, 1990a), children with SLI should be impaired on all tasks in the present study involving the temporary retention of verbal information. Findings of greater SLI impairments on tasks involving processing would be consistent with a generalized processing deficit (e.g., Kail, 1994; Bishop, 1992), whereas greater decrements in tasks tapping verbal processing may indicate some domain-specificity. A further possibility is that findings may reflect both a verbal storage and generalized processing deficit: If this is the case, greater SLI deficits may be expected to occur on tasks tapping both verbal storage, and processing of either verbal or visuospatial information.

4.1: Method

4.1.1: Participants

Forty-two children participated in three groups in the present study: 14 children with SLI, 14 chronological age-matched control children (age-match), and 14 language age-matched control children (language-match). Each group comprised 8 males and 6 females. The mean ages of the groups were as follows: SLI, 10 years; 2 months (*SD*=1.85, *R*=7;8-12;10), age-match, 10;3 (*SD*=1.56, *R*=7;4-12;10), and language-match, 6;6 (*SD*=1.48, *R*=4;9-10;9). All of the children had participated in the previous studies (chapters 2-3) and met the criteria outlined in chapter 3, section 3.1.1 at the time of recruitment, 9 - 12 months prior to their participation in the present study. It should be noted that one child in the SLI group had withdrawn from the project at the time of the present study, and this child together with the matched age- and language-mates were withdrawn from the original group of 45 (chapter 3). The age-match group was matched to the SLI group on sex and age, and the language-match group on sex and BPVS-II raw score (mean difference in raw score=2.43, *SD*=2.06). Descriptive statistics for all screening measures completed by the children are summarized in Table 4.1.

Table 4.1

Descriptive statistics for standardized measures as a function of group

Measure	Score	Participant Group					
		SLI		age-match		language-match	
		M	*SD*	*M*	*SD*	*M*	*SD*
Ravens	RS	25.71_a	4.81	29.43_a	3.32	20.14_b	3.98
	SS	102.64	9.57	111.86	10.87	108.36	8.08
GFTA-2	RS	5.14_a	2.32	0.50_b	1.61	5.50_a	5.08
	SS	92.64	3.25	102.86	5.35	103.64	5.75
BPVS-II	RS	66.71_a	12.76	101.79_b	16.85	66.57_a	14.21
	SS	76.86	9.23	104.50	13.23	105.29	10.75
TROG	RS	11.71_a	2.43	17.79_b	1.42	12.64_a	2.82
	SS	76.79	7.89	107.57	10.49	100.64	10.43
EVT	RS	68.64_a	11.04	91.07_b	18.37	60.50_a	9.65
	SS	80.07	12.32	98.93	14.44	100.00	11.42
Recalling Sentences	RS	17.50_a	3.37	42.14_b	12.11	20.71_a	7.79
	ScS	3.21	0.58	8.43	2.79	6.64	2.56
Short Form BPVS	RS	15.64_a	3.50	21.57_b	4.13	15.29_a	2.64
	SS	73.86	18.65	103.00	18.54	102.43	10.06

Note. Ravens = Raven's Coloured Progressive Matrices; BPVS-II = British Picture Vocabulary Scales 2; TROG = Test for Reception of Grammar; EVT = Expressive Vocabulary Test; RS = raw score; SS = standard score (M=100, SD=15); ScS = scaled score (M=10, SD=3). For raw scores, means in the same row that do not share subscripts differ at p<.01 in the Tukey HSD comparison.

In order to ensure that the language skills of the children in the present study remained consistent with the recruitment criteria, all participants completed an additional language measure at the time of the present study, the *BPVS Short Form* (Dunn, Dunn, Whetton, & Pintillie, 1982). The SLI group continued to perform in the deficit range on this test scoring almost 2 *SD* below the standardized mean on average, and the typically developing groups scored in the average range (see Table 4.1). The SLI and language-match groups remained closely matched on raw score at the time of the present study on this measure, $t(26)=0.305$, $p>.05$. In one-way ANOVAs, the age-match group had significantly higher raw scores than the SLI group on all measures ($p<.05$) except Raven's Matrices ($p=.053$), whereas the SLI and language-match groups did not differ significantly on raw score on any of the screening measures ($p>.05$) except the Raven score ($p=.002$), with the SLI group achieving a higher score. It should be noted that although all participants scored in the average range on the Raven's Matrices, small but reliable differences occurred between the groups. For this reason, Raven score was entered as a covariate in *post hoc* analyses of group differences.

4.1.2: Procedure

Each child was tested individually in a quiet room in school in three 30-minute sessions. The experimental tasks were completed in two sessions following the procedures of Bayliss et al. (2003). Another session followed in which the short form of the BPVS (Dunn et al., 1982), and other tasks not reported here were completed. The experiment consisted of two processing (verbal and visuospatial) and two storage (verbal and visuospatial) tasks, and four complex memory measures derived from combining these processing and storage tasks. In individual sessions, children completed either both same-domain complex memory measures and the storage-only measures, or both cross-domain complex memory measures and the processing-only measures. The presentation order of the complex memory tasks was counterbalanced within groups. In each session, the storage tasks were completed after the complex memory tasks, and the processing tasks before.

The tasks were identical to those used by Bayliss et al. (2003), and employed the same computer software programmed in Hypercard (Apple Computer, Inc., 1993) presented by means of a Macintosh Powerbook computer. In each task, a fixed pattern of nine squares located randomly on a grey screen background served as the template. Each square appeared either as small or large, in one of nine colours (red, blue, green, yellow, white, pink, purple, brown, orange), and with one of the digits from 1 to 9 centered in each in black. The colour of each square varied across tasks, while the numbers within each square varied after each presentation with the constraint that target numbers appeared equally often in each position. On each trial, one of the large squares and some of the small squares were presented with a bevelled edge, created by highlighting a section of the square circumference. The location of the large bevelled square was balanced across serial position.

Complex span tasks. In the two complex memory tasks involving verbal processing, children were required to make associations between verbal object names presented auditorily at the onset of the visual display and the colour typically identified with each object, and to find the square of the select colour (e.g., the child hears “bananas”, and points to the yellow square). At that point, demands varied depending on whether the complex memory task involved verbal or visuospatial storage. In tasks involving verbal storage, the child was asked to verbalize the number in the middle of the cued square and remember that number for recall at the end of the trial. In tasks involving visuospatial storage, the children were asked to point to the appropriate square and remember its location for recall at the end of the trial. In the complex memory tasks involving visuospatial processing, children were required to scan the display to locate the large square with the bevelled edge. The child was then required either to identify the target number within the square and remember the number (verbal storage) or to point to the square and remember its location (visuospatial storage) for later recall.

Each time a child indicated a square either by pointing to it (visuospatial storage) or saying its number (verbal storage), the experimenter clicked on the appropriate square regardless of whether it was the correctly cued square, and wrote down the verbalized number (if present). The computer recorded the mouse clicks for later evaluation. After each click, the target square remained on the screen, and all other numbers and colours disappeared from the display until the stimulus presentation ended after 5500 ms. If a child failed to make a response within 4500 ms, the correct square was presented by itself for the remaining 1000 ms, and in the case of verbal storage, the child was encouraged to verbalize the number in the square. After each processing and storage episode, the screen was cleared before the next stimulus presentation. Trials in all four tasks increased in span length from two to seven processing and storage episodes, with three trials at each span level. Three additional two-item trials were given at the beginning of each task as practice, but data from these were not included in the analysis. The end of each trial was signalled by the presentation of a screen with the location of the squares outlined in black but all the same size and with all colours and numbers removed from the display. At this point, the child was asked either to recall the numbers (verbal storage) or point to the positions of the squares (visuospatial storage) in the order of presentation. A trial was scored as correct if the children recalled the numbers or positions in correct serial order. Testing was terminated if a child made errors on all three trials at a given span length.

All 66 object names employed in the verbal processing task (Bayliss et al., 2003) reliably cued their associated colour in pilot testing (see Appendix A, Bayliss et al., 2003). Recordings of a male voice speaking the individual object names were adjusted to a uniform 1000 ms length by adding silent intervals to the start of shorter object names. This stimulus pool was used in both of the complex span tasks involving verbal processing, although the order of presentation of object names was varied across the two tasks.

Processing speed. The visuospatial and verbal processing speed were measured in visual search tasks completed on the same displays used in the complex span tasks, but with the set sizes of three, six, or nine squares ‘active’ in each display as indicated by being presented in colour, small or large, and with or without a bevelled edge, while the remaining squares were an uncoloured, black outline of fixed size. In the verbal processing task, the child was asked to locate the colour associated with the given object name as quickly as possible, and in the visuospatial processing task, the child was asked to locate the large square with the bevelled edge as quickly as possible, and the experimenter clicked on the indicated squares. Following each response, a blank screen with a fixation cross in the center appeared, and the experimenter clicked on the cross to proceed to the next search trial. Responses as well as reaction times (RTs) from the onset of each trial were recorded by the computer. Each square position was cued once in each set size condition. In the verbal processing task, 27 of the object names used in the complex span tasks were presented auditorily in one of three set size conditions.

Storage tasks. Verbal storage ability was measured in a digit span task in which sequences of digits were presented visually in 48-point Helvetica font in the center of the screen. Stimuli were shown for 1000 ms, with an interstimulus interval of 300 ms. The numbers 1 – 9 were organized into trials so that each number appeared equally often in each serial position. List length increased from two to nine items with three trials at each list length. To make the storage requirements comparable to those in the complex span tasks, the children were required to verbalize each number as it appeared on the screen and then verbally recall the numbers at the end of each trial in serial order. Testing continued until the child failed all three trials at a given list length.

Visuospatial storage was measured in a block recall task in which the black outlines of the nine squares were presented on a grey computer screen in the same positions as in the complex span tasks, and sequences of squares were presented by showing each filled in with black for 1000 ms, with an interstimulus interval of 300 ms. The nine positions were cued equally often in each serial position across trials, and easily identifiable spatial patterns were avoided. List length increased from one to nine items with three trials at each list length. At the end of each trial, the children were required to recall the positions in the correct serial order by pointing to the circles. Testing continued until the child failed all three trials at a given list length.

Scoring and analysis. The score taken for the storage tasks and complex memory measures was the number of trials correct. For each of the processing measures, the median RT of items in each set size (3, 6, 9) was calculated and then averaged for each child, thereby reducing the effects of outliers present in the data. In the Bayliss et al. (2003) study, values of Cronbach's α ranged from 0.76 to 0.85 for these measures.

4.2: Results

Descriptive statistics for all experimental measures are provided in Table 4.2. Separate analyses were conducted on the data from the processing, storage, and complex memory tasks.

Table 4.2

Descriptive statistics as a function of all experimental measures and groups

	Participant group					
	SLI		age-match		language-match	
Measure	*M*	*SD*	*M*	*SD*	*M*	*SD*
Processing speed:						
Verbal RT	2919.05	318.01	2409.92	240.97	3258.33	565.36
Visuospatial RT	2940.48	557.28	2561.90	577.90	3416.27	878.56
Storage:						
Verbal –						
serial recall	9.57	1.79	10.64	2.27	8.21	2.22
free recall	10.21	1.53	12.36	2.53	8.93	2.62
Visuospatial –						
serial recall	9.50	2.24	10.29	2.43	6.79	1.93
free recall	12.00	2.63	12.64	3.20	7.86	2.11
Complex memory:						
Verbal-verbal	4.21	1.97	7.36	3.56	2.21	2.04
Verbal-visuospatial	8.79	2.36	9.93	2.40	5.14	1.92
Visuospatial-verbal	7.00	2.39	9.21	3.53	5.14	3.63
Visuospatial-visuospatial	8.29	3.34	7.64	3.13	4.71	2.23

Note. RT = reaction time. The complex memory tasks are labelled by processing domain followed by storage domain.

4.2.1: Processing Speed

An ANOVA was conducted on RT scores as a function of group and domain (verbal, visuospatial). The main effect of group was significant, $F(2,39)=11.330$, $p<.001$, $\eta^2_p=0.34$. Bonferroni-adjusted *post hoc* pairwise comparisons confirmed that the age-match group had faster RTs than the SLI ($p<.05$) and language-match groups ($p<.001$), and that the SLI and language-match groups did not differ ($p>.05$). The main effect of domain, $F(1,39)=0.033$, $p>.05$, $\eta^2_p=0.001$, and the interaction between domain and group, $F(2,39)=0.740$, $p>.05$, $\eta^2_p=0.04$, were not significant. This pattern of significance was obtained also in a corresponding ANCOVA in which Raven raw score was entered as covariate. These results indicate that the SLI group processed information more slowly overall than the age-match group regardless of domain.

4.2.2: Storage tasks

An ANOVA including all three participant groups was performed on the mean trials correct for the storage measures as a function of group and domain (verbal, visuospatial). The main effect of group was significant, $F(2,39)=11.363$, $p<.001$, $\eta^2_p=0.37$. Pairwise comparisons revealed that the scores of the language-match group were significantly lower than both the SLI ($p<.01$) and age-match groups ($p<.001$), and that the SLI and age-match groups did not differ ($p>.05$). Nonsignificant terms included the main effect of domain, $F(1,39)=2.198$, $p>.05$, $\eta^2_p=0.05$, and the interaction between domain and group, $F(2,39)=0.979$, $p>.05$, $\eta^2_p=0.05$.

The absence of group differences between the SLI and age-match groups on the verbal storage task in the previous analysis was not anticipated; verbal short-term memory impairments for SLI groups have been found in many previous studies (e.g., chapter 2; Edwards & Lahey, 1998; Gathercole & Baddeley, 1990a; Montgomery, 1995a). One possible reason for the absence of an SLI deficit is that the storage tasks employed in the present work used only three trials per list length, which may have constrained variability in the data and reduced the sensitivity of the measures to group differences. To test this, the data were rescored according to a free recall criterion in which trials were counted as correct if all items were reproduced regardless of order. Descriptive statistics for free recall in the storage tasks are provided in Table 4.2. In the ANOVA performed on these data, the main effect of group was significant, $F(2,39)=15.059, p<.001, \eta^2_p=0.44$, with a significant interaction between domain and group, $F(2,39)=3.338, p<.05, \eta^2_p=0.15$. The main effect of domain was nonsignificant, $F(1,39)=0.545, p>.05, \eta^2_p=0.01$. Analysis of simple effects confirmed that the scores of the SLI group were significantly lower than the age-match group for verbal ($p<.05$) but not visuospatial free recall ($p>.05$), whereas the SLI group achieved higher scores than the language-match group on the visuospatial ($p<.001$) but not verbal measure ($p>.05$). The scores of the age-match group were significantly higher than those of the language-match group for both verbal ($p<.01$) and visuospatial free recall ($p<.001$). When the simple effects were repeated as ANCOVAs in which Raven raw score was entered as covariate, the scores of the SLI group remained significantly higher than the language-match group for the visuospatial task ($p<.01$), and lower than the age-match group for the verbal task ($p=.090, \eta^2_p=0.11$). None of the other comparisons approached significance ($p>.20$, $\eta^2_p<.06$, all cases). These results indicate that the SLI group performed more poorly than the age-match group on the verbal but not visuospatial storage task, and better than the language-match group on the visuospatial but not verbal storage task.

4.2.3: Complex Memory

An ANOVA was conducted on complex memory scores as a function of processing domain (verbal, visuospatial), storage domain (verbal, visuospatial), and group. The main effect of storage domain was highly significant, $F(1,39)=16.895$, $p<.001$, $\eta^2_p=0.30$, reflecting higher scores on the tasks involving visuospatial storage. The significant effect of processing domain, $F(1,39)=6.886$, $p<.05$, $\eta^2_p=0.15$, arose from superior performance on tasks involving visuospatial processing. The effect of group was significant, $F(2,39)=14.255$, $p<.001$, $\eta^2_p=0.42$, as was the interaction between group and storage domain, $F(2,39)=16.895$, $p<.001$, $\eta^2_p=0.30$. There was also a significant interaction between processing and storage domain, $F(2,39)=37.554$, $p<.001$, $\eta^2_p=0.49$. Nonsignificant interactions were found between processing domain and group, $F(2,39)=2.900$, $p=.067$, $\eta^2_p=0.13$, and between group, and processing and storage domain, $F(2,39)=0.219$, $p>.05$, $\eta^2_p=.01$. For the interaction between processing and storage domain, simple main effects analysis comparing complex memory tasks collapsed across groups revealed that scores on same-domain tasks were significantly lower than cross-domain tasks ($p<.001$). It should be noted that the interaction between storage domain and group was the only significant term found in a corresponding ANCOVA in which Raven score was entered as covariate.

Figure 4.1. Mean trials correct and 95% confidence intervals for complex memory tasks requiring verbal or visuospatial storage for each participant group.

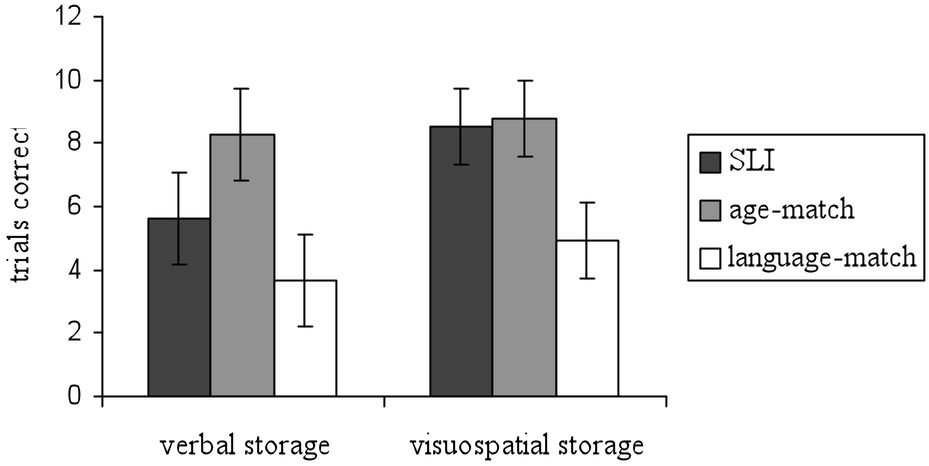


Figure 4.1 displays the mean scores and 95% confidence intervals for the interaction between storage domain and group, with scores collapsed across processing domain. In separate analyses comparing the SLI group with each of the control groups, the interaction between storage domain and group remained significant in both cases: SLI vs. age-match, $F(1,26)=5.578$, $p<.05$, $\eta^2_p=0.18$; SLI vs. language-match, $F(1,26)=4.988$, $p<.05$, $\eta^2_p=0.16$. Analysis of simple effects revealed that the performance of the SLI group was significantly lower than the age-matched group on the complex memory tasks involving verbal ($p<.05$), but not visuospatial storage ($p>.05$). For the comparison with the language-match group, the SLI group achieved significantly higher scores on the complex memory tasks involving visuospatial storage ($p<.001$) with a moderate effect size ($\eta^2_p=0.45$), and verbal storage ($p<.05$) with a small effect size ($\eta^2_p=0.16$). It is clear from Figure 4.1 that the SLI group performed much more poorly on the complex memory tasks involving verbal than visuospatial storage

with no overlap in the 95% confidence intervals around the means of the respective storage domains. Both typically developing groups, on the other hand, showed considerable overlap in performance across domains.

Further analyses investigated whether group differences in complex memory performance could be predicted on the basis of differences in the individual measures of storage capacity and processing speed. In the first set of ANCOVAs, the serial recall verbal storage measure was entered as covariate. The interaction between storage domain and group was significant when comparing the SLI group with both the age-match, $F(1,25)=4.392$, $p<.05$, $\eta^2_p=0.15$, and language-match groups, $F(1,25)=6.875$, $p<.05$, $\eta^2_p=0.22$. In a corresponding ANCOVA performed with the free recall storage score entered as covariate, the interaction between storage domain and group was nonsignificant for the comparison between the SLI and age-match groups, $F(1,25)=3.880$, $p=.06$, $\eta^2_p=0.13$, but was significant for the SLI and language-match groups, $F(1,25)=6.305$, $p<.05$, $\eta^2_p=0.20$. When the independent processing speed measures were entered in ANCOVAs either as single covariates (i.e., verbal or visuospatial processing) or as two covariates (i.e., both verbal and visusopatial processing), the storage domain and group interaction remained significant for the SLI vs. language-match groups, $F(1,24)=7.030$, $p<.05$, $\eta^2_p=0.23$, but not the SLI vs. age-match groups, $F(1,24)=1.229$, $p>.05$, $\eta^2_p=0.05$. In a final ANCOVA set comparing the SLI and language-match groups, verbal storage and both independent processing measures were entered as covariates; the interaction between storage domain and group remained significant regardless of the verbal storage measure employed, serial recall: $F(1,23)=10.780$, $p<.01$, $\eta^2_p=0.32$, free recall: $F(1,23)=9.384$, $p<.01$, $\eta^2_p=0.29$.

4.3: Discussion

This study investigated the nature of storage and processing constraints underlying the deficits in performance that have been widely documented in SLI for complex memory span. A group of children with SLI were found to be slower at processing verbal and visuospatial information compared with typically developing children of the same age, and also were impaired in verbal short-term storage. The children with SLI were impaired as well on complex memory tasks involving verbal storage, irrespective of whether storage was accompanied by concurrent verbal or visuospatial processing activity. This impairment was found when the SLI group was compared with younger children with similar language abilities, and could not be accounted for by independently measured abilities in either verbal storage or processing speed.

The present findings are both consistent with and extend previous research. SLI deficits in the current work included slower processing of both verbal and visuospatial material, and impaired verbal storage. Taken separately, these deficits are consistent with reports of generalized slowing (e.g., Kail, 1994; Miller et al., 2001) and impaired verbal short-term memory in SLI (e.g., Gathercole & Baddeley, 1990a). However, neither of these deficits on its own was sufficient to explain the substantial impairment in complex memory performance when verbal short-term memory was paired with verbal processing. Consider first the generalized slowing. The SLI group recalled information as accurately as their same-age peers in the complex memory measures tapping their preserved visuospatial but not impaired verbal storage skills. So, despite generalized slowing in the processing portion of the task, the children with SLI had the capacity to complete the task as expected for their age when the additional demands for storage did not tax additionally impaired resources (see also, chapter 3).

Similarly, the decrement of the SLI group in verbal storage was considerably less marked than their impairments for other tasks. In other studies, poor verbal short-term memory in SLI has not always led to impaired performance on tasks tapping verbal storage: Gillam, Cowan, and Marler (1998) reported SLI deficits in a digit recall task under conditions of visual presentation, but not combined auditory and visual presentation. It appears that when task demands are low and confined to verbal storage only, children with SLI sometimes can attain age-appropriate levels of performance.

It is clear that these dual deficits impair performance to some extent, but it is the combination of both a generalized slowing in processing and a verbal storage impairment that had such a drastic impact on the children with SLI in the present study. Recall accuracy was reduced in the SLI group even relative to younger control children with similar language abilities when task requirements included verbal storage and either verbal or visuospatial processing, and this deficit could not be accounted for by impairments in general processing or verbal storage alone. Other findings as well suggest that a verbal short-term memory deficit could not account for the complex memory decrement of the SLI group in the present study. In a recent longitudinal study of children with a persistent history of very poor verbal short-term memory that extended between 4 and 8 years of age, performance on verbal complex memory tasks was found to be in the low average range four years later (Gathercole, Tiffany, et al., 2005).

It seems likely that the combined impact of these deficits may be particularly problematic for children with SLI.

The present results point to an account of SLI that encompasses both generalized slowing (Kail, 1994), and a verbal short-term memory impairment (Gathercole & Baddeley, 1990a). A ‘slow processing plus verbal storage’ deficit has particular advantages over unidimensional models: It is consistent not only with current evidence pertaining to SLI deficits in both processing and storage, but the clinical profile of SLI as well. It is well recognized that SLI is a heterogeneous disorder with deficits disproportionately affecting but not limited to linguistic skill. The vulnerability of verbal storage in the context of a generalized deficit provides clear mechanisms both for the specific language learning difficulty characteristic of SLI, and more general deficiencies commonly observed such as cognitive impairments in reasoning or problem solving (e.g., Ellis Weismer, 1991; Nippold, et al., 1988) or poor scholastic attainment (e.g., Arvedson, 2002; Fazio, 1999). In addition, individual variability both in the degree of impairments across the continuums of processing and storage skills, as well as the context of particular demands for processing and storage to which individuals may be exposed would give rise to considerable individual variation in the disorder. It should be noted that the suggestion that a single deficit model is insufficient to account for SLI is not new: Bishop and Snowling (2004) have proposed that dual deficits in phonological and semantic skills differentiate SLI from forms of dyslexia.

The current findings complement those of Bayliss et al. (2003). Both studies provide evidence that complex memory span performance is constrained by factors related both to domain-general processing and domain-specific storage. These results are entirely compatible with the multiple-component working memory model (Baddeley & Hitch, 1974; Baddeley & Logie, 1999). According to this model, performance on the processing component of complex memory tasks is supported by the domain-general central executive, while the storage component is supported by the domain-specific resources of either the phonological loop or visuospatial sketchpad.

In this study, children with SLI had exceptional difficulty holding verbal material in mind when engaged in any type of concurrent information processing. This result is particularly compelling because it appears to provide a very interesting account of how an impairment specific to the language learning mechanism might arise in the context of generalized slowing. The performance of most everyday cognitive tasks involves the simultaneous storage and maintenance of information – there are in fact few occasions when one's only task is to remember simple information for immediate recall. If then, at every step of the way, individuals with SLI are processing information more slowly and failing to hold verbal items in mind, their acquisition and development of language may be greatly impaired.

Chapter 5

Nonword Repetition: A Comparison of Tests

Children with Specific Language Impairment (SLI) experience particular difficulties in repeating multisyllabic nonwords such as /wʊgə'læmɪk/ or /nɔɪtaʊf/. This finding has led to widespread interest both in the cognitive processes tapped by nonword repetition and its diagnostic utility. The studies presented in chapters 5 and 6 explore factors that may influence nonword repetition both in children with SLI and typically developing children. The purpose of the present study was to compare the performance of a group of children with SLI on two of the most widely used tests of nonword repetition – the Children’s Test of Nonword Repetition (CNRep, Gathercole & Baddeley, 1996), and the Nonword Repetition Test (NRT, Dollaghan & Campbell, 1998).

Nonword repetition deficits in SLI have been established in several independent research studies over the past two decades (e.g., Botting & Conti-Ramsden, 2001; Conti-Ramsden, 2003b; Dollaghan & Campbell, 1998; Edwards & Lahey, 1998; Ellis Weismer, et al., 2000; Gathercole & Baddeley, 1990a; Gray, 2003; Kamhi & Catts, 1986; Kamhi, et al., 1988; Montgomery, 2004; Marton & Schwartz, 2003; Norbury, et al., 2002; Sahlen, et al., 1999). Difficulty repeating nonwords has been found in children with SLI relative to younger, typically developing children with matched language abilities (Edwards & Lahey, 1998; Gathercole & Baddeley, 1990a; Montgomery, 1995a), and in children with a history of SLI whose oral language is no longer distinguishable from age peers (Bishop, et al., 1996; Conti-Ramsden, et al., 2001; Stothard, et al., 1998). Multisyllabic nonword repetition has been found to be one task more impaired in children with SLI than children with reading impairments although these groups perform similarly on many other tasks (Kahmi & Catts, 1986; Kamhi et al., 1988).

Many studies have employed one of two particular tests of nonword repetition. The CNRep (Gathercole & Baddeley, 1996) is widely used in the UK, and the NRT (Dollaghan & Campbell, 1998) has been employed in many US-based studies of SLI. Consider first findings from studies employing the CNRep. Deficits on the CNRep in children with SLI have been found to have a strong genetic basis. In two twin studies, Bishop and colleagues demonstrated that the characteristic CNRep deficit in SLI is highly heritable and distinguishable from the auditory temporal processing difficulties that are also characteristic of the disorder (Bishop et al., 1996; Bishop, Bishop, Bright, James, Delaney, & Tallal, 1999). Recently, nonword repetition deficits in SLI assessed by a preliminary version of the CNRep (Gathercole, Willis, Emslie, & Baddeley, 1994) have been linked in particular with abnormalities of chromosome 16q (SLI Consortium, 2002, 2004). Based on the pattern of results from their twin study, Bishop et al. (1996) suggested that the CNRep provides an effective phenotypic marker of SLI. Conti-Ramsden and colleagues included CNRep in an evaluation of potential clinical markers of SLI in a group of 5-year-old children (Conti-Ramsden, 2003b) and a group of 11-year-old children with a previous history of SLI (Conti-Ramsden, et al., 2001). Results indicated that nonword repetition provided a useful clinical marker, although the more difficult task of sentence repetition was a more effective marker in the older age group. Also, nonword repetition was found be a useful clinical tool in identifying young children with slow language development who are potentially at risk of persistent SLI (Conti-Ramsden & Hesketh, 2003).

The NRT has also been shown to be an excellent discriminator of children with language impairment. Dollaghan and Campbell (1998) reported that poor NRT performance was 25 times more likely to occur in a clinically referred group of children receiving language intervention than children with typical language development. Diagnostic accuracy of the NRT in this study surpassed that of the Spoken Language Quotient of the Test of Language Development-2 (Newcomer & Hammill, 1988). Ellis Weismer et al. (2000) used the NRT to examine nonword repetition in a population based sample of school age children and reported that poor scores were 6.5 times more likely to occur in children receiving language intervention. In a study of 4-year-old children with and without a history of language delay, poor NRT performance was over 3 times more likely in the group with a positive history for language delay (Thal, Miller, Carlson, Vega, 2005). An important feature of the NRT is that this measure has been found to be less culturally biased than typical standardized language tests in that scores have not been found to distinguish typically developing white American from African American children (Campbell, Dollaghan, Needleman, & Janosky, 1997; see also, Rodekhor & Haynes, 2001; Washington & Craig, 2004). Further, scores on both the NRT and CNRep are reported to be largely independent of performance IQ in children with both typical and atypical language development (Conti-Ramsden et al., 2001; Ellis Weismer et al. 2000; Gathercole et al., 1994).

Although there is substantial evidence that children with SLI show similar patterns of deficit on both the CNRep and NRT, no direct comparisons of performance profiles on the two tasks have been made as yet for a common sample, and the purpose of the present study was to do this. One aim of the study was to examine whether children with SLI and children with typically developing language skills differ equally strongly on both measures. The second motivation for the study was to explore factors that may account for any features of performance specific to the individual tests. The two tests differ in their composition in several ways that are directly relevant to current theoretical accounts of the nonword repetition deficit in SLI. The CNRep (Gathercole & Baddeley, 1996) contains 40 nonwords that range in length from two to five syllables. Some of the stimuli contain consonant clusters (e.g., /'blɒntə'steɪpɪŋ/, /'prɪndl/), the majority contain weak syllables with a reduced vowel (e.g., /'hæm*pənt*/, /'tæ*fləst*/), and many include lexical components and morphemes (e.g., ‘pen’ in /'*pen*l/ or ‘ing’ in /'blɒntə'steɪp*ɪŋ*/). Nonwords are spoken with a natural prosodic pattern characteristic of English words of that particular length. Each nonword repetition attempt is scored on-line as either correct or incorrect. In contrast, the NRT (Dollaghan & Campbell, 1998) consists of 16 nonwords ranging in length from one to four syllables. All stimuli contain single consonants only drawn from a set without late-acquired phonemes that are acoustically salient, and do not include any constituent syllables corresponding to lexical items. The nonwords are spoken with equal stress on each syllable, facilitated by the inclusion of tense vowels only (e.g., /teɪvak/). Repetition accuracy is scored from transcriptions as the percentage of phonemes correctly repeated in appropriate positions (see also, Gray, 2003; Sahlen et al., 1999).

Why should these differences matter? The reason is that the two nonword sets differ in many of the factors that have been suggested to play a role in the nonword repetition deficit in SLI. An account of this deficit advanced by Gathercole and Baddeley (1990a) is that it reflects an underlying impairment of verbal short-term memory. The evidence in support of this claim is as follows. First, the children with SLI in this study also performed poorly on conventional measures of short-term memory such as digit span and word recall (see also chapter 2; Montgomery, 1995a), consistent with abundant evidence from other developmental and neuropsychological studies that nonword repetition and digit span are highly correlated with one another (see Gathercole et al., 1994; Baddeley, Gathercole, et al., 1998, for reviews). Second, this group showed the greatest repetition decrement for the lengthiest nonwords, which were four syllables in length. Decreased recall accuracy for memory sequences that have lengthy articulatory durations is a hallmark of verbal short-term memory, and is typically attributed to temporal decay of the phonological representations in a short-term store (Baddeley, et al., 1975; Cowan, et al., 1991). By this account, the greater repetition decrement for lengthier nonwords in children with SLI could arise either from accelerated rates of decay prior to output, or from inadequate encoding in the short-term store. Third, it was argued that the unfamiliarity of the phonological structure of nonwords forces participants to rely heavily on temporary phonological representations to support their repetition attempt, preventing the reliance on activated lexical representations that arises in memory tasks using familiar verbal stimuli (e.g., Hulme, et al., 1991).

Note that according to the original Gathercole and Baddeley (1990a) short-term memory account of nonword repetition, children with SLI should be disadvantaged in repeating any lengthy nonwords due to the lack of availability of compensatory lexical support. However, more recent research has established that even memory for nonwords can benefit from some support from knowledge of the lexical and phonotactic composition of the language (Roodenrys & Hinton, 2002; Vitevitch & Luce, 2005). Mechanisms for such support may include lexical and sublexical processing by which internal phonological representations of sound sequences are activated to encode the stimuli (Gupta & MacWhinney, 1997; Martin & Gupta, 2004), or the process of redintegration by which incomplete memory representations are filled in at the time of retrieval (Gathercole, et al., 1999; Gathercole, et al., 1991). Such lexical and redintegrative processes may be expected to compensate to some degree for the short-term memory deficit in SLI. If this is the case, the nonword repetition impairment of the SLI group in the present study may be expected to be greater on the NRT than the CNRep, due to the lesser opportunity for knowledge-based support in the former than the latter test stimuli.

Several alternative accounts of the nonword repetition deficit in SLI have since been advanced. Children with less extensive vocabulary knowledge may be at a disadvantage in nonword repetition because they have fewer opportunities to supplement temporary representations in short-term memory due to their more impoverished repertoire of lexical and sublexical knowledge (Snowling, et al., 1991) or less robustly abstracted representations of individual phonemes (Edwards, et al., 2004). It may be, also, that children with SLI have less efficient mechanisms either for using lexical knowledge to support short-term memory or for creating representations within long-term memory leading to difficulties in repeating uncommon phoneme sequences even relative to children with similar vocabulary skills. Perhaps, then, the source of the nonword repetition deficit in children with SLI is their more poorly differentiated representational system arising from less efficient lexical mediation. On this basis, children with SLI in the present study should be more disadvantaged on the CNRep than the NRT, as the stimuli employed incorporate many more lexical and morphological elements that could potentially benefit children with more extensive vocabulary knowledge or more efficient lexical mediation processes.

Nonword repetition accuracy is also undoubtedly influenced by the quality of speech output processes (Wells, 1995), and this is an area in which children with SLI are known to have problems. Individuals with SLI have more difficulty producing well-organized and stable rhythmic speech motor movements than typically developing children of the same age (Goffman, 1999, 2004); this may provide one possible cause of the nonword repetition deficit. Sahlen et al. (1999) found that maturity of phonological output processes was strongly associated with nonword repetition scores in a sample of young children with language impairment. Also, children with SLI have been reported to be differentially impaired in repeating nonwords containing consonant clusters, which place greater demands on speech output processes due to the need to coordinate a variety of articulatory gestures within a syllable when compared to typically developing (Bishop et al., 1996; Briscoe, et al., 2001) and hearing impaired groups (Briscoe et al., 2001). Although the present sample of children with SLI excluded individuals with marked articulatory or phonological impairments, it is possible that the children had more subtle problems with speech-motor output that could jeopardize the accuracy of their nonword repetition attempts. In the present study, such difficulties may be reflected as greater SLI decrements in the repetition of the clustered consonants and later-developing phonemes of the CNRep nonwords than the single consonants and earlier-developing phonemes in the NRT stimuli.

In this study, two tests of nonword repetition, the Children's Test of Nonword Repetition (CNRep; Gathercole & Baddeley, 1996) and the Nonword Repetition Test (NRT; Dollaghan & Campbell, 1998), were completed by three groups of children: school-age children with SLI, and two groups of typically developing children, one matched for age, and one for language abilities. The study aimed to examine the pattern of group differences in performance across both measures to assess factors that may contribute to the nonword repetition deficit in SLI. Performance was generally expected to be superior on the CNRep than the NRT for all groups due to the inclusion of more wordlike nonwords on the CNRep that provide opportunities for support by existing lexical knowledge. Poorer repetition on both tests was predicted for the SLI group, at least relative to the control group matched for age.

In addition, it was hypothesized that the pattern of SLI decrements across the tests may reflect the relative contribution to the poor nonword repetition in SLI of three factors, short-term memory, lexical mediation, and speech output. Specific predictions for the present study corresponding to each of these cognitive processes are as follows: (1) Disproportionate impairments on the NRT would be consistent with a verbal short-term memory account of the nonword repetition impairment in SLI due to the reduced opportunities for support via lexical and phonotactic redintegration processes, as would greater SLI deficits on the lengthier nonwords of both tests. (2) Greater SLI deficits on the CNRep, particularly on the highly wordlike stimuli, would point to poor lexical mediation processes as an important factor. (3) Poorer performance by the SLI group on the CNRep than the NRT may also point to deficits in motor speech output as a factor, as would findings of greater SLI deficits on the nonwords of the CNRep with a high proportion of consonant clusters.

5.1: Method

5.1.1: Participants

Thirty-six children participated in three groups in the present study: 12 children with SLI, 12 chronological age-matched control children (age-match), and 12 language age-matched control children (language-match). Each group comprised 8 males and 4 females. The mean age of the groups was as follows: SLI, 9 years; 8 months (*SD*=1.70, *R*=7;3-12;5), age-match, 9;9 (*SD*=1.64, *R*=7;0-12;5), and language-match, 6;1 (*SD*=1.61, *R*=4;4-10;4). The present study took place at the same time as the study reported in chapter 3, and involved the same children. It should be noted that three children from the original group (chapter 3) failed to attempt repetition on over 50% of trials in the present study, two children in the SLI group and one child in the language-match group. Rates of responses for all other participants were at least 95%. The three children and their matched cohorts in the other two participant groups were removed from the sample.

Descriptive statistics for the criterion measures completed by the children in the present study are summarized in Table 5.1. SLI group means for the

BPVS-II, TROG, and EVT were approximately 1.25 *SD* below the standardized mean, and more than 2 *SD* below the mean for Recalling Sentences. For each test, the proportion of children who scored below the 1.25 *SD* cutoff was as follows: BPVS-II, 0.75; TROG, 0.67; EVT, 0.58; Recalling Sentences, 1.0. Individual language profiles conformed closely to the group pattern with nine participants scoring more than 1.25 *SD* below the mean on three or four of the language measures. The mean difference in raw score of the BPVS-II for the SLI and language match groups was 2.5 (*SD*=2.07).

Table 5.1

Descriptive statistics for standardized criterion measures, articulation rate, and digit recall for all groups

Measure	Score	Participant Group					
		SLI		age-match		language-match	
		M	*SD*	*M*	*SD*	*M*	*SD*
Raven's	RS	25.33_a	5.05	29.67_a	3.31	20.58_b	4.10
Matrices	SS	102.83	10.37	114.00	9.09	109.75	7.90
GFTA-2	RS	5.50_a	2.28	0.58_b	1.73	5.92_a	5.33
	SS	92.25	3.11	103.17	5.75	103.50	6.20
BPVS-II	RS	66.00_a	13.71	103.50_b	17.64	65.50_a	15.06
	SS	77.08	10.00	107.17	12.34	104.83	11.10
TROG	RS	11.58_a	2.39	17.75_b	1.55	12.50_a	3.03
	SS	77.08	7.82	108.58	11.03	101.25	11.19
EVT	RS	68.58_a	10.64	93.08_b	19.14	59.58_a	10.18
	SS	81.67	11.26	101.83	13.47	100.42	11.81
Recalling	RS	17.08_a	3.37	43.50_b	12.15	20.08_a	8.22
Sentences	ScS	3.25	0.62	9.00	2.45	6.33	2.64

Note. Raven's Matrices = Raven's Coloured Progressive Matrices; BPVS-II = British Picture Vocabulary Scales, 2nd ed.; TROG = Test for Reception of Grammar; EVT = Expressive Vocabulary Test; RS = raw score; SS = standard score (*M*=100, *SD*=15); ScS = scaled score (*M*=10, *SD*=3). For raw scores, means in the same row that do not share subscripts differ at $p<.01$ in the Tukey HSD comparison.

In one-way ANOVAs, group differences were found for raw scores on all measures at $p<.001$, with the exception of the Raven score ($p=.018$). The age-match group had significantly higher raw scores on all measures at $p<.01$ except the Raven's ($p=.043$), whereas the SLI and language-match groups did not differ significantly on raw score on any of the screening measures except the Raven's ($p=.025$), with the SLI group achieving higher scores. On the basis of this group difference, Raven raw score was used as a covariate in all parametric analyses of group differences.

5.1.2: Procedure

The measures reported in the present study were completed in three individual half hour sessions in a quiet room in the child's school. In addition to the language screening measures outlined in chapter 3, each child completed the *Children's Test of Nonword Repetition* (CNRep; Gathercole & Baddeley, 1996), and the *Nonword Repetition Test* (NRT; Dollaghan & Campbell, 1998). The language screening measures were completed in two sessions at the time of recruitment. Once recruitment was complete, the nonword repetition tasks were administered in a single session, together with the visuospatial memory measures reported in chapter 3. The order of tasks for this session was as follows: Completion of two visuospatial tasks, the CNRep, two visuospatial tasks, and the NRT. Responses for all measures were recorded on a digital minidisk player.

Nonword repetition tasks. For each of the nonword repetition tasks, children were told that they would hear some made-up words and be asked to repeat each one exactly as they had heard it. Each word was played once followed by a three second pause during which the child responded.

The *CNRep* (Gathercole & Baddeley, 1996) involves the presentation of 40 non-words, divided equally into two-, three-, four- and five-syllable items that the child is required to repeat (see Appendix 1). Half of the non-words contain consonant clusters (e.g., /'blɒntə'steɪpɪŋ/) and the remainder have single consonants only (e.g., /wʊgə'læmɪk/). The non-words are presented in a fixed random order by audio tape recording. Typical English stress patterns are used in the presentation.

The *NRT* (Dollaghan & Campbell, 1998) consists of 16 nonwords, four stimuli each contained one, two, three, and four syllables (Appendix 2). The nonwords are constructed from a limited set of phonemes (11 consonants, 9 vowels) excluding late developing sounds. The nonwords follow an alternating consonant-vowel structure, and none of the syllables correspond to English lexical items. Only tense vowels are used, and therefore the stress patterns of the nonwords are unlike typical English words in that they have no weak syllables. A detailed description of the criteria guiding the development of the NRT is provided by Dollaghan and Campbell (1998). A fixed random order of nonwords was adopted for this study in order to ensure consistency across both tests. The nonwords were presented by digital audio recording of a native British adult female speaker following the phonetic transcription and pronunciation guidelines described by Dollaghan and Campbell (1998).

Scoring and reliability. All responses to the nonword repetition tests were scored at the phoneme level in order to provide comparable data across both tests. Each phoneme was scored as correct or incorrect in relation to the target phoneme. Phoneme substitutions and omissions were scored as incorrect; correctly articulated phonemes with slight distortions were scored as correct. As several research groups in the field do not score phoneme additions as errors (e.g., Dollaghan & Campbell, 1998; Ellis Weismer et al., 2000), phoneme additions were not counted as errors in the present study. In cases of syllable omissions, an anchoring procedure based on vowel alignment was used to align the syllable sequences as closely as possible to the target syllable prior to individual phoneme scoring. For each nonword repetition task and each nonword length, the number of phonemes correct was divided by the total number of phonemes in the set resulting in a percent phonemes correct at each nonword length. These values were used to compute a mean percent phonemes correct for the entire set for each task. This method of calculating a total score avoids disproportionate contribution by the longest nonwords to the total score (Kane, et al., 2004).

Scoring was completed by the author, a trained Speech-Language Pathologist. A second listener trained in phonetic transcription with no knowledge of the participants' language status and group transcribed 14% of the samples independently (five audiotaped responses for each test). Phoneme percentages of inter-rater agreement ranged from 79-90%, with an average of 86% for the NRT, and from 84-96%, with an average of 90% for the CNRep. In addition, four audiotaped responses from participants completing the NRT for each participant group (33%) were transcribed a second time independently by the author, four months after the initial transcriptions. Phoneme percentages of intra-rater agreement ranged from 90-100%, with an average of 98%.

5.2: Results

Table 5.2

Mean percent phonemes correctly repeated (SD) at each nonword length for each task and participant group

Measure	Length	Participant Group					
		SLI		age-match		language-match	
		M	*SD*	*M*	*SD*	*M*	*SD*
CNRep	2 syllables	92.99	6.56	96.54	2.25	95.91	3.76
	3 syllables	91.17	5.06	95.78	2.48	90.91	4.83
	4 syllables	82.50	9.18	91.83	4.79	85.05	8.30
	5 syllables	81.30	10.86	93.12	4.71	85.65	8.90
	M	86.99	6.97	94.32	2.68	89.38	5.79
NRT	1 syllable	90.28	7.81	93.75	7.22	86.11	12.48
	2 syllables	85.83	10.41	92.08	6.20	80.42	14.21
	3 syllables	65.18	18.84	85.71	12.56	60.42	23.47
	4 syllables	58.56	15.96	81.48	6.84	59.95	13.48
	M	74.96	10.17	88.26	4.77	71.72	13.96

Descriptive statistics in percent phonemes correct are presented for both nonword repetition tests and all participant groups in Table 5.2. As the two tasks differed in numbers of stimuli, scores were expressed as percentage values for the purposes of comparison across tests and syllable lengths. For all participant groups, mean scores were higher for the CNRep than the NRT at equivalent syllable lengths. Accuracy decreased with increase in nonword length for all groups, except for the longest length of the CNRep (see also, Gathercole et al., 1994). The decline in repetition accuracy with increasing length was most marked on the NRT. Means across participant groups were similar for shorter nonword lengths, but the age-match group scored more highly at the longer lengths. The SLI group means were lower than both control groups on the CNRep, but lower than the age-match group only on the NRT.

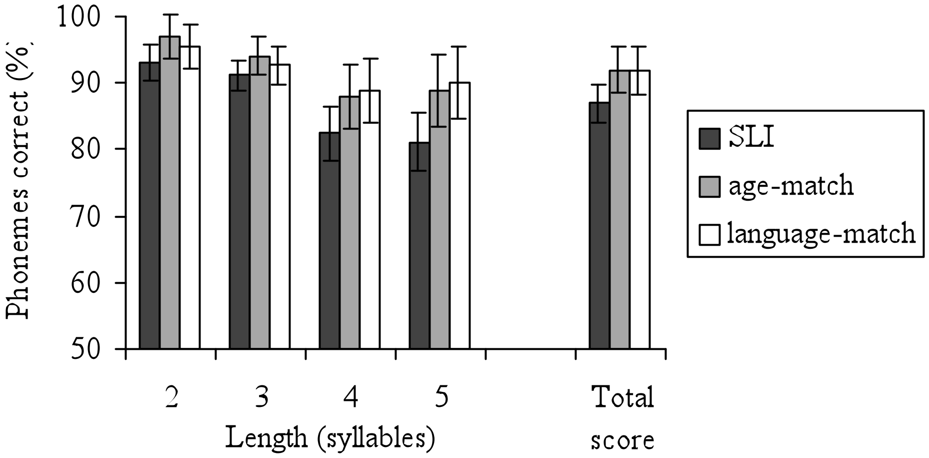
A rationalized arcsine transform function was used to convert all scores into interval level data for statistical analysis (Studebaker, 1985). Group differences were evaluated in a series of analysis of covariances with Raven's raw score entered as covariate. Prior to each ANCOVA, a test for homogeneity of regression slopes was completed (Wildt & Aohla, 1978). In all cases, the interaction between group and Raven score was not significant ($p>.05$) indicating that there were no group differences in the Raven slope function.

5.2.1: Group comparisons: Nonword repetition

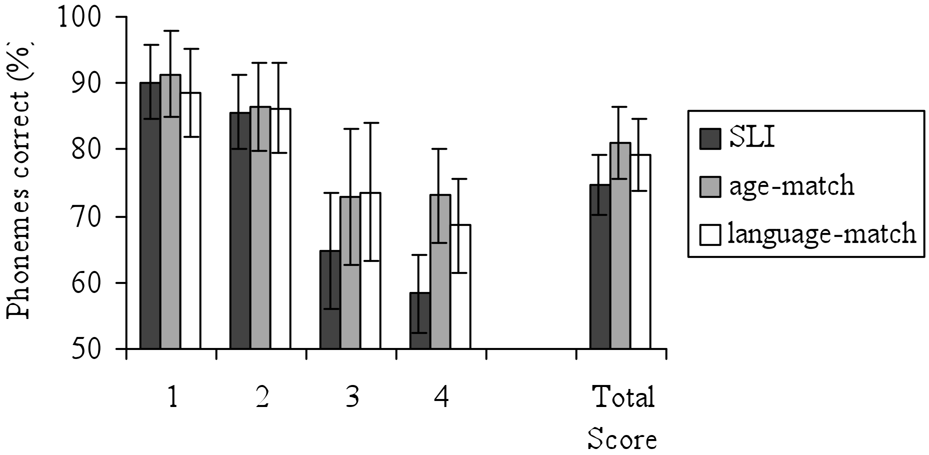
Mean phoneme accuracy scores on both nonword repetition measures adjusted for Raven score for all participant groups are summarized in Figure 5.1. Separate univariate ANCOVAs were used to assess group differences in the total score of each test for each of the three groups with Raven score as covariate. For the CNRep, the main effect of group was significant, $F(2,32)=4.212, p<.05, \eta_p^2=0.21$, and Raven score was a significant covariate, $F(1,32)=7.637, p<.01, \eta_p^2=0.19$. Planned contrasts revealed that the SLI group performed more poorly than both of the control groups ($p<.05$, both cases). For the NRT, Raven score was a significant covariate, $F(1,32)=24.949, p<.001$, $\eta_p^2=0.44$, but the main effect of group failed to reach significance, $F(2,32)=2.525, p>.05, \eta_p^2=0.14$. Cognitive development had a significant effect on performance on both tests, however the effect size of the Raven covariate was considerably larger for the NRT (0.44) than the CNRep (0.19). Thus when scores were adjusted for individual differences in cognitive ability, the SLI group performed more poorly than both of the control groups on the CNRep, but at equivalent levels to the control groups on the NRT.

Figure 5.1. Mean percent phonemes correctly repeated with 95% confidence interval bars for each participant group for each stimulus length and total score on the (a) CNRep and (b) NRT.

(a) CNRep



(b) NRT



In the next set of analyses, the performance of the three groups across syllable lengths was compared for each nonword repetition test separately in mixed-model ANCOVAs as a function of group and syllable length, with Raven score as covariate (see Figure 5.1a). For the CNRep scores, there were significant main effects of length, $F(3,96)=12.806$, $p<.001$, $\eta^2_p=0.29$, and group, $F(2, 32)=3.456$, $p<.05$, $\eta_p^2=0.18$. Raven score was a significant covariate, $F(1,32)=5.94$, $p<.05$, $\eta_p^2=0.16$, and interacted significantly with length, $F(3,96)=6.684$, $p<.001$, $\eta_p^2=0.17$. The interaction between length and group was not significant, $F(6,96)=1.246$, $p>.05$, $\eta_p^2=.07$. The main effect of length reflects a significant decrease in repetition accuracy with increasing length, and the interaction of length with Raven score reflects a significant developmental trend in nonword repetition. Planned contrasts between groups revealed that the SLI group performed more poorly than the age-match group ($p<.05$). In comparison to the analysis on the CNRep total score, the contrast with the language-match group in this analysis marginally failed to reach significance ($p=.057$), which likely reflects the reduced power associated with this group by length analysis.

In the corresponding analysis on the NRT phoneme accuracy scores across syllable lengths (Figure 5.1b), the main effect of length was significant, $F(3,63)=8.337$, $p<.001$, $\eta_p^2=0.21$, due to the decrease in repetition accuracy with increasing stimulus length. Raven score was a significant covariate, $F(1,32)=22.429$, $p<.001$, $\eta_p^2=0.41$, and interacted significantly with length, $F(3,96)=6.145$, $p<.01$, $\eta_p^2=0.16$. The interaction between length and group was not significant, $F(6,96)=1.095$, $p>.05$, $\eta_p^2=.06$. The main effect of group did not reach significance, $F(2,32)=2.103$, $p>.05$, $\eta_p^2=0.17$, although the effect size was similar to that found for the main effect of group in the corresponding CNRep analysis (0.18).

The failure to find a group effect in the NRT total score or syllable length analyses appears to contradict previous findings (e.g., Dollaghan & Campbell, 1998; Ellis Weismer et al., 2000), however the statistical comparisons involved in these studies differed from the current work in important ways: These other studies compared larger groups, of similar ages, and without covarying nonverbal abilities. In order to provide directly comparable results, the NRT scores of the SLI and age-match groups in the present study were compared in an ANOVA as a function of group and syllable length. All terms were significant: group, $F(1,22)=16.080$, $p<.001$, $\eta_p^2=0.42$; length, $F(1,22)=19.728$, $p<.001$, $\eta_p^2=0.47$; length and group, $F(1,22)=3.154$, $p<.05$, $\eta_p^2=0.13$. It should be noted that when the analysis was repeated with Raven score as covariate, the main effects (both group and length) remained significant. In agreement with previous studies, these results indicate that the SLI group did perform more poorly than the age-match group with similar nonverbal abilities. Level of cognitive development as indexed by Raven score, however, did have a greater effect on NRT than CNRep performance. It is possible that there was insufficient power to detect a group difference when all three groups (age range 4 to 12 years) were included in the analysis due to the small sample size.

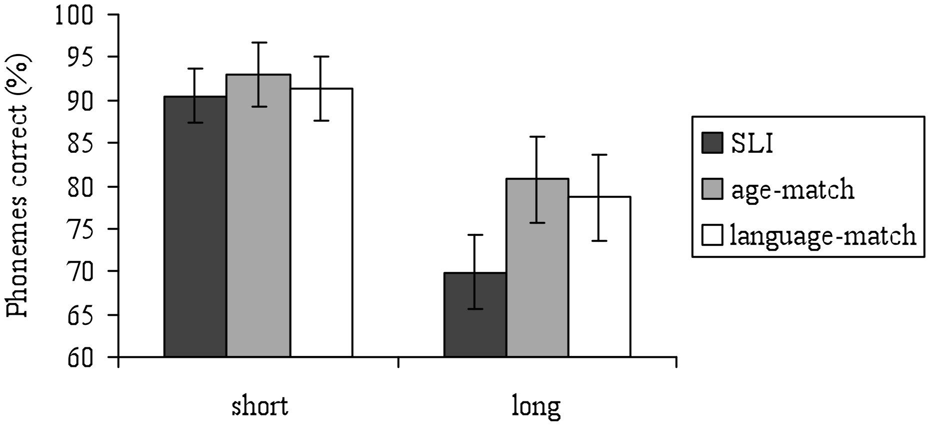
To summarize the findings for the group comparisons of total scores and syllable lengths, the SLI group performed more poorly than the age-match group on the CNRep and NRT but was impaired relative to the language-match group only on the CNRep once scores were adjusted for nonverbal abilities.

5.2.2: Group comparisons: Specific features

Nonword length. Although the performance decrement of the SLI group was greater for the longest nonwords in the present study, the preceding analyses did not establish a significant increase in the SLI deficit with lengthier nonwords as has been found in previous studies (e.g., Dollaghan & Campbell, 1998; Gathercole & Baddeley, 1990a). One possibility is that the analyses reported above lacked sufficient power to detect an interaction given the presence of four levels in the length variable together with a small sample size. In order to increase the power for detecting such an interaction, group performance was compared on the shortest (1- or 2-syllables) and longest (4- or 5-syllables) item lengths in a single ANCOVA as a function of group, length, and test, with Raven score as covariate. In the case of the longest items of the CNRep (4- & 5-syllables) and shortest items of the NRT (1- & 2-syllables) where two syllable lengths in the test comprised either long or short nonwords respectively, accuracy was taken as the average score computed for the two appropriate lengths. As in the previous analyses, there was a main effect of length, $F(1,32)=38.363$, $p<.001$, $\eta_p^2=0.55$, and group, $F(2,32)=3.563$, $p<.05$, $\eta_p^2=0.18$. There was also a main effect of test, $F(1,32)=29.315$, $p<.001$, $\eta_p^2=0.48$ in favour of the CNRep. Raven score was a significant covariate, $F(1,32)=10.053$, $p<.01$, $\eta_p^2=0.24$, and interacted significantly with length, $F(1,32)=12.458$, $p<.001$, $\eta_p^2=0.28$, and test, $F(1,32)=10.194$, $p<.01$, $\eta_p^2=0.24$, but the three-way interaction between Raven's, test, and length was not significant, $F(1,32)=0.050$, $p>.05$, $\eta_p^2=0.002$. Neither the interaction between test and length, $F(1,32)=0.033$, $p>.05$, $\eta_p^2=0.001$, test and group, $F(2,32)=0.340$, $p>.05$, $\eta_p^2=0.021$, or test, length, and group, $F(2,32)=2.619$, $p>.05$, $\eta_p^2=0.14$, were significant. Importantly, there was a significant interaction between length and group, $F(2,32)=4.794$, $p<.05$, $\eta^2_p=0.23$. Analysis of simple effects revealed that group differences occurred on the long nonwords, $F(2,32)=7.398$, $p<.01$,

η^2_p=0.32, but not the short nonwords, *F*(2,32)=0.491, *p*>.05, η^2_p=0.03. In the case of the long nonwords, the SLI group performed more poorly than both the age-match (*p*<.01) and language-match (*p*<.05) control groups. Figure 5.2 displays adjusted means for this interaction, and establishes that the decline in performance on the long versus short items was more marked for the SLI as compared to the other two groups.

Figure 5.2. Mean percent phonemes correctly repeated with 95% confidence interval bars for short and long nonword items for each participant group.



Wordlikeness. The possible contribution of poor lexical knowledge to the nonword repetition deficit in SLI was examined in a *post hoc* analysis of the CNRep. One way of investigating the degree of lexical mediation in nonword repetition is by comparing repetition accuracy on stimuli rated as low and high in wordlikeness (Gathercole, et al., 1991; Gathercole, 1995). The wordlikeness ratings obtained by Gathercole et al. (1991) on a 5-point scale ranging from 1 (very unlike a real word) to 5 (very like a real word) were used to create two subsets of 14 CNRep items matched for number of phonemes, syllables, and consonant clusters (see Appendix 3). One set contained nonwords of low-rated wordlikeness, whereas the other contained high wordlikeness items. Mean percent phoneme accuracy and standard deviations for each participant group on the high and low wordlikeness sets are summarized in Table 5.3. The pattern of slightly higher repetition accuracy for the high- than the low-wordlikeness set was consistent for all groups, although the difference was minimal for the age control group. In the ANCOVA performed on the scores for the wordlikeness sets between groups with Raven score as covariate, the main effect of wordlikeness failed to reach significance, $F(1,32)=3.653$, $p>.05$, $\eta_p^2=0.10$. There was a significant main effect of group, $F(2,32)=4.441$, $p<.05$, $\eta_p^2=0.22$, but not a significant wordlikeness by group interaction, $F(2,32)=0.163$, $p>.05$, $\eta^2_p=0.01$. Raven score was a significant covariate, $F(1,32)=8.314$, $p<.01$, $\eta_p^2=0.21$, but did not interact significantly with wordlikeness, $F(1,32)=0.980$, $p>.05$, $\eta_p^2=0.03$. The SLI group had lower scores than both the age- ($p<.05$) and language-match groups ($p<.05$) in planned contrasts. In the present data, then, there was no difference in sensitivity to wordlikeness across the SLI and control groups.

Table 5.3

Mean percent phonemes correctly repeated (SD) for subsets of CNRep items for all participant groups

Subset Type	Participant Group					
	SLI		age-match		language-match	
	M	*SD*	*M*	*SD*	*M*	*SD*
			Wordlikeness			
High wordlikeness	88.85	5.87	94.43	2.71	91.11	3.60
Low wordlikeness	83.38	10.58	92.74	4.57	86.26	7.76
			Articulatory Complexity			
Single Consonants	89.68	6.09	93.41	3.36	89.98	4.81
Consonant Clusters	82.36	15.76	94.68	1.87	90.12	5.29

Articulatory complexity. A second *post hoc* analysis of the CNRep data explored the possible effects of speech motor output processes on nonword repetition, as indexed by the presence of consonant clusters. As clusters are more complex to produce than single consonants, a finding of increased SLI deficits with stimuli containing these structures may point to motoric differences as a source of the nonword repetition deficits. In the present study, two subsets of 15 CNRep items were created matched for syllable length (see Appendix 4). Items in the single consonant group had an alternating consonant – vowel structure only, with no adjacent consonants even across syllable boundaries, whereas items in the consonant clusters group had clusters in at least half of their syllables. The subsets included 5 items at the 2-syllable length, 5 at the 3-syllable length, and 5 at the 4-syllable length. The 5-syllable length was not included because there were insufficient tokens of 5-syllable items without consonant clusters for comparison. Mean percent phoneme accuracy and standard deviations are shown in Table 5.3 for each group on the lists containing words with either single consonants or consonant clusters. Mean scores were lower on the consonant clusters than single consonant list for all groups, but the reduction in performance across lists was greatest for the SLI group. Results of the ANCOVA comparing articulatory complexity, and participant groups on phoneme accuracy with Raven score as covariate revealed one significant effect, a significant interaction between articulatory complexity and group, $F(2,32)=4.321, p<.05, \eta^2_p=0.21$. Raven score was a significant covariate, $F(1,32)=6.960, p<.05, \eta^2_p=0.13$, but did not interact significantly with articulatory complexity, $F(1,32)=0.398, p>.05, \eta^2_p=0.01$. Neither the main effects of articulatory complexity, $F(1,32)=0.224, p>.05, \eta^2_p=0.01$, or group, $F(2,32)=2.823, p>.05, \eta^2_p=0.15$, reached significance. Analysis of simple effects indicated that the groups differed on the consonant cluster, $F(2,32)=6.268, p<.01, \eta^2_p=0.28$, but not the single consonant nonword list, $F(2,32)=0.529, p>.05, \eta^2_p=0.03$. Pairwise comparisons confirmed that the SLI group performed at a lower level on the consonant cluster word list than either the age-match ($p<.01$) or the language-match ($p<.05$) groups.

5.3: Discussion

Nonword repetition deficits were found in the present study in children with SLI when compared across two measures of nonword repetition, the Children's Test of Nonword Repetition (CNRep; Gathercole & Baddeley, 1996) and the Nonword Repetition Test (NRT; Dollaghan & Campbell, 1998). The performance of the SLI group was impaired relative also to younger typically-developing children with similar language abilities once scores were adjusted for differences in general cognitive ability on the CNRep only. The magnitude of the impairment of the SLI group increased for lengthier and for more articulatory complex nonwords, relative to both typically developing groups. Of the two tests, the NRT was influenced to a greater degree by differences in developmental cognitive ability.

In line with previous findings, the results indicate that children with SLI have a disproportionate difficulty in repeating novel phonological sequences. Why is this? One proposal has been that an impairment of short-term memory may underlie the nonword repetition deficit in SLI (Gathercole & Baddeley, 1990a). Consistent with this suggestion, the nonword repetition deficit of the SLI group relative to the control groups was greatest for the longest nonwords (see also, Dollaghan & Campbell, 1998; Edwards & Lahey, 1998; Ellis Weismer, et al., 2000; Montgomery, 1995a). According to Baddeley et al. (1998), short-term memory plays a key role in learning new words by generating a phonological representation of brief and novel speech events that mediates the creation of a phonological entry within the long-term lexical store. Children with SLI therefore may have more difficulty learning new words because their short-term memory representations are inadequate.

The present findings cannot, however, be readily accommodated solely by a verbal short-term memory deficit in SLI. One crucial difference between the two repetition tests is that nonwords in the NRT do not incorporate any lexical or sublexical units, whereas items in the CNRep include sublexical and morphological components. On this basis, it would be expected that the NRT would have a greater dependence on short-term memory, due to the reduced opportunities for support via lexical and phonotactic redintegration processes. In line with this view, repetition accuracy was greater on the CNRep than the NRT even though the order of test administration (NRT second) may have been expected to benefit the NRT (Gray, 2003). If a short-term memory deficit alone underpins the nonword repetition deficit in SLI, children with SLI should be more disadvantaged on the NRT than the CNRep as a consequence of lack of opportunity for successful redintegration. Contrary to this prediction, the SLI group deficit was found to be greater on the CNRep. The children with SLI obtained lower scores on the CNRep than both groups of control children, whereas the typically developing groups did not differ from one another. In contrast, performance of the SLI and language groups was equivalent on the NRT even when adjusted for nonverbal ability.

One explanation for this finding is that children with SLI have less efficient lexical mediation processes to support short-term memory in the course of nonword repetition. The finding of a greater SLI deficit on the CNRep is consistent with this view. In addition, though, it would be expected that the SLI group should show a reduced advantage to nonwords high in wordlikeness, whereas in fact no group deficits in sensitivity to wordlikeness were observed. It should, however, be acknowledged that performance approached ceiling levels for the age-match control children in part of this analysis, which could potentially have masked a greater benefit of high wordlikeness in this group. Further systematic investigation is required to resolve this issue.

One factor that does appear to have contributed a differential effect on the SLI group is the articulatory complexity of the nonword stimuli. It may be that the greater SLI deficit on the CNRep arises in part from the inclusion of consonant clusters in contrast to the NRT. Consistent with this notion, only the SLI group showed a marked decline in repetition accuracy on the nonwords containing consonant clusters, in line with both Bishop et al.'s (1996) and Briscoe et al.'s (2001) findings. Thus although in all of these studies the children with language impairments had no gross motor speech deficits, they were further disadvantaged in nonword repetition when the articulatory demands of the stimuli were particularly complex. There are at least two possible interpretations of this finding: The children with SLI may have less robust phonological representations for these relatively uncommon phoneme combinations, although recent evidence from children with phonological impairments has not supported this suggestion (Munson, et al., 2005). Alternatively, the children with SLI may have difficulty forming the novel phonological sequences required in nonword repetition. In line with this view, Goffman (2004) reported that children with SLI have difficulty producing well-organized and stable rhythmic speech motor movements, which may conceivably affect their ability to repeat nonwords. It is possible, then, that the (poor) speech motor output skills of children with SLI contribute in part at least to their difficulties in nonword repetition.

The two nonword repetition tasks also differed in the strength of their associations with the nonverbal reasoning measure that is widely interpreted as tapping general cognitive maturity, Raven's Matrices. Scores on the NRT were much more highly associated with performance on the Raven test than CNRep scores, suggesting that the former nonword repetition task may be more closely linked to general cognitive development than the CNRep. One limitation of the present study was the small sample size together with the large age range of participants across groups (4 to 12 years), which may account for the failure to detect a group difference when all three groups were compared on the test more sensitive to cognitive abilities, the NRT. One further possibility is that the SLI group may have benefited from a differential practice effect resulting in greater improvements on the second repetition test administered (NRT) relative to the control groups (Gray, 2003). SLI deficits on the CNRep, on the other hand, were demonstrable even for the small sample sizes involved in the present study, as they were for the NRT when the children with SLI were compared to their age peers.

In summary, this study confirms previous findings of poor nonword repetition in children with SLI for two tests of nonword repetition, the CNRep (e.g., Bishop et al., 1996; Conti-Ramsden, 2003b; Gathercole & Baddeley, 1990a) and the NRT (e.g., Dollaghan & Campbell, 1998; Ellis Weismer et al., 2000). In line with a verbal short-term memory account of the deficit, the SLI group had more difficulty holding novel phonological forms in mind as reflected by the increased magnitude of their repetition impairment for longer nonwords. The test with the greater ability to identify SLI deficits was the CNRep in which items incorporate sublexical units, grammatical morphemes and consonant clusters. The children with SLI had more difficulty repeating words with increased articulatory complexity, but benefited from lexical similarity of nonwords to the same extent as typically developing children. These results suggest that verbal short-term memory alone may not provide a full explanation of the nonword deficit in SLI. It is possible that there are multiple origins to the deficit in nonword repetition - verbal short-term memory, lexical knowledge, output processes, as well as others. The CNRep, therefore, may better reflect the nonword repetition deficit in SLI because it incorporates stimuli that tap several of these components.

One problem with the present study, however, is that although the measures employed do tap different processes and stores of knowledge, neither one was developed specifically to test the influence of these variables on nonword repetition performance. The study presented in chapter 6 was designed to investigate the role of factors other than short-term memory in nonword repetition by comparing group performance in nonword repetition and serial recall of phonologically matched syllable sequences.

Chapter 6

Nonword Repetition and Serial Recall: Equivalent measures of Verbal Short-term Memory?

The immediate repetition of single nonword forms has attracted a great deal of interest because the abilities to repeat nonwords and to learn language are very closely related to one another: individuals who perform poorly on nonword repetition typically struggle to learn the phonological form of language (see section 1.3.1). While the evidence linking nonword repetition and the learning of novel phonological forms is now extensive, the cognitive processes suggested to underlie nonword repetition are a matter of debate. Nonword repetition was first proposed as a relatively pure index of verbal short-term memory capacity (Gathercole & Baddeley, 1989, 1993). According to this view, repetition of nonwords requires more reliance on the temporary storage of phonological representations in short-term memory because of the reduced availability of long-term lexical knowledge to support the unfamiliar phonological forms. Other researchers have focused on other constraints on nonword repetition performance including lexical knowledge (Snowling, et al., 1991), phonotactic probability (Edwards, et al., 2004), phonological sensitivity (e.g., Bowey, 1996; Metsala, 1999), and output phonology (e.g., Stackhouse et al., 2005; Wells, 1995).

One line of evidence in support of the short-term memory account of nonword repetition is the reliable correlations found between nonword repetition and more conventional measures of temporary verbal storage abilities such as digit span in both developmental and neuropsychological studies (e.g., Gathercole & Baddeley, 1989; Gathercole et al., 1999; Gathercole et al., 1992; Gupta, 2003; Gupta, MacWhinney, Feldman, & Sacco, 2003). One potential problem for this argument, however, concerns the discrepancy in findings between nonword repetition and standard serial recall measures for the same group of 20 children with SLI reported in chapter 2: 70% of the children were impaired on measures of serial recall, whereas every child tested had a deficit in nonword repetition. Furthermore, the absolute magnitude of the nonword repetition deficit was much greater than that on serial recall (see also, Conti-Ramsden, 2003b). It must be acknowledged, though, that the nonword repetition and serial recall measures employed in chapter 2 differed substantially (i.e., in length, familiarity, and phonological properties) precluding direct comparisons. The aim of the present study was to compare serial recall and nonword repetition performance directly by using matched phonological content across tasks in children with SLI and typically developing groups.

Serial recall is a paradigm that has been employed extensively to study the temporary retention of verbal material (e.g., Baddeley, et al., 1975; Conrad, 1964; Henson, Norris, Page, & Baddeley, 1996). As reviewed in section 1.2.1, immediate repetition of items for ordered recall forms a classic ‘serial position curve’ where recall starts very accurately, decreases throughout the list, and then improves towards the end of the list. Incorrect responses are classified as either item or order errors (e.g., Henson, et al., 1996; Pickering, et al., 1998). Examples of item errors include omissions (no response) and intrusions (an item that was not in the present list is recalled). Order errors occur when an item that was in the original sequence migrates in the recall protocol to an incorrect position.

Error patterns in serial recall depend on the nature of the to-be-remembered lists. As in the majority of serial recall studies, when lists contain items sampled from a small and highly familiar stimulus pool such as letter names, order rather than item errors dominate (Aaronson, 1968; Bjork & Healy, 1974), whereas when lists are constructed from an open stimulus vocabulary (Gathercole, et al., 2001) or include nonwords (Jefferies, Frankish, & Lambon Ralph, 2006), the majority of errors are item rather than order. Item fragmentation has been noted in serial recall when list items are relatively unfamiliar. For example, Gathercole et al., (1999) found that partially accurate recalls containing one or two phonemes from the target were more common in memory lists comprised of unfamiliar than familiar lexical forms. In a study of the serial recall of monosyllabic nonword items, Treiman and Danis (1988; see also, Treiman, 1995) reported that phoneme rather than whole-item movements comprised the majority of errors. Most errors involved phoneme recombinations that preserved syllabic structure. Vowels were recalled more accurately than consonants (see also, Ellis, 1980; Gathercole et al., 1999), and vowels and consonants rarely, if ever, substituted for one another. Consistent with earlier data concerning item migrations at the whole-item level (e.g., Lee & Estes, 1977), phoneme movement errors covered smaller distances than would be predicted if no memory for serial position had been retained.

It is widely accepted that this pattern of serial recall behaviour reflects both a system for storing phonological aspects of list items such as the phonological loop (see section 1.2.1) and a mechanism for encoding and retrieving order information. In computational models developed to simulate these data, serial order is encoded by associating a temporal tag with either a specific list position (Page & Norris, 1998) or an individual list item (Burgess & Hitch, 1992, 1998; Brown, Preece, & Hulme, 2000). Typically, these models have been based on a closed set of items and lack the capacity to account for the more detailed phoneme error profiles described above. As yet, only Hartley and Houghton (1996) have aimed to develop a model of serial recall for unfamiliar phonological forms that represents stimuli at both the syllable and phoneme level.

Relatively few studies have provided comparable examinations of nonword repetition data. One important study has replicated the classic serial position curve in nonword repetition: Gupta (2005) demonstrated primacy and recency effects in nonword repetition for both naturally spoken stimuli and nonwords composed from the concatenation of monosyllables. These findings do indeed suggest that common sequencing mechanisms may underlie both nonword repetition and serial recall. Phoneme substitutions (item errors) are a relatively common error pattern in nonword repetition (Gathercole et al., 1992), and tend to share articulatory features with the target (Bisiacchi, Cipolottis, & Denes, 1989; Caramazza, Miceli & Villa, 1986).

Although much evidence points to the high degree of association between serial recall and nonword repetition, differences between the paradigms exist even in the present study which employed matched stimuli: sequences of consonant-vowel (CV) syllables were presented either in isolation for serial recall (e.g., /fau/… /mɔɪ/… /tʃi/) or as a single coarticulated nonword for repetition (e.g., /faumɔɪtʃi/). Some of the differences between tasks may be expected to benefit nonword repetition. For example, it is possible that multisyllabic nonwords convey more information about sound structure, which would lead to a recall advantage for nonword repetition. One potential source of the additional information in the acoustic signal for naturally-spoken nonwords is coarticulation, the modification of the speech signal associated with a particular sound by prior and subsequent phonetic segments. Coarticulation extends across vowel-vowel segments (e.g., Nijland, Maassen, van der Meulen, Gabreels, Kraaimaat, & Schreuder, 2002) and even word boundaries (e.g., Coleman, 2003), and significantly influences word recognition processes (e.g., Nguyen, 2001). Coarticulatory cues across successive syllables will therefore be a feature of naturally spoken nonwords but not of isolated syllable sequences representing the same phonological structure. A second additional source of information present in spoken nonwords but absent in syllable sequences is prosodic contour. Prosody represents a complex set of cues including vowel reduction, pauses and amplitude patterns, and can interact with coarticulation (e.g., Cho, 2004). Stress pattern is known to exert a powerful influence on nonword repetition, with the majority of errors located in unstressed syllables (e.g., Roy & Chiat, 2004). One further difference in favour of nonword repetition is overall stimulus duration, which will be shorter for nonword repetition potentially creating opportunities for more rapid responding or rehearsal.

Other factors differentiating the paradigms may benefit serial list recall. Intensity and duration patterns of consonant and vowel segments are known to vary with syllable structure (Lehiste, 1970), position (Yoo & Blackenship, 2003), and stress pattern (Cho & McQueen, 2005). It is expected that each syllable will have a higher level of acoustic-phonetic salience when produced singly in a serial sequence than in equivalent multisyllabic productions, which may convey an advantage in immediate serial recall. Also, output demands are considerably less for serial recall than nonword repetition: the multisyllabic responses required for nonword repetition are associated with more rapid and coarticulated speech gestures.

It is clear from the preceding discussion that while both serial recall and nonword repetition may provide an index of short-term memory, they also differ in several important ways. The purpose of the present study was to examine the extent to which performance is influenced by these additional factors in both children with SLI and typically developing children. Because the syllabic content of the sequences employed in the present study was the same in the two tasks, the short-term memory load is equivalent. Thus, if verbal storage abilities alone are sufficient to account for performance on both tasks, repetition accuracy in nonword repetition and serial recall should be comparable. More accurate repetition in nonword repetition may point to the importance of the additional coarticulatory and prosodic information available in the multisyllabic stimuli whereas superior serial recall performance may reflect the acoustic salience of the input or low output demands associated with this paradigm.

It is important to consider the particular case of SLI in the present study. As reviewed in chapter 5, nonword repetition deficits in SLI have been extensively documented (e.g., Conti-Ramsden, 2003b; Dollaghan & Campbell, 1998; Edwards & Lahey, 1998; Ellis Weismer, et al., 2000; Gathercole & Baddeley, 1990a). One account of these findings is that the nonword repetition deficit in SLI arises from an impairment of verbal short-term memory (Gathercole & Baddeley, 1990a; see also, chapter 5). The present study provides a test of this hypothesis: If the severe impairment of nonword repetition characterizing children with SLI reflects solely an impairment of short-term memory, the SLI group should show deficits relative to typically developing children to an equivalent extent in both nonword repetition and serial recall. However, children with SLI may be impaired in other areas that differentiate the experimental paradigms such as in processing rapidly changing signals (e.g., Tallal & Piercy, 1973a, b; Tallal, et al., 1981) and coordinating speech motor output (Goffman, 1999, 2004). A finding that the SLI group is differentially impaired on one of the experimental tasks would implicate factors additional to short-term memory that differentiate the two paradigms.

6.1: Method

6.1.1: Participants

Participants were 13 children with SLI (8 males, 5 females), 13 typically developing children matched for sex and chronological age (age-match), and 13 typically developing children matched for sex and language ability (language-match). The mean age of the groups was as follows: SLI, 10 years; 5 months (*SD*=1.77, *R*=7;10-13;0), age-match, 10 years; 5 months(*SD*=1.54, *R*=8;4-13;0), and language-match, 6 years; 9 months (*SD*=1.56, *R*=5;4-11;1). The children in the age-match group were matched to those in the SLI group on sex and chronological age (mean age difference in months=3.97, *SD*=2.58), and the language-match group on sex and raw score of the BPVS-II (mean difference in raw score=2.4, *SD*=2.16). All of the children had participated in the previous studies (chapters 2-5) and met the criteria outlined in chapter 3 section 3.1.1 at the time of recruitment, 9 - 12 months prior to their participation in the current work. The present study was conducted around the time of the study reported in chapter 4 at which time one child in the SLI group had withdrawn from the project (see section 4.1.1). Another child in the SLI group refused to attempt repetition on over 50% of the trials in the present study. These children and their matched age- and language-mates were withdrawn from the original group of 45 (chapter 3) resulting in three groups of 13 in the present study. Response rates for all other participants in the study were at least 95%.

Descriptive statistics for all screening measures are provided in Table 6.1. In order to ensure that the language skills of the children in the present study remained consistent with the recruitment criteria, all participants completed an additional language measure at the time of the present study, the *BPVS Short Form* (Dunn, et al., 1982) as described in chapter 4, section 4.1.2. The SLI group continued to perform in the deficit range on this test scoring almost 2 *SD* below the standardized mean on average, and the typically developing groups scored in the average range (see Table 6.1). The SLI and language-match groups remained closely matched on the BPVS short form score, $t(24)=0.432$, $p>.05$. In one-way ANOVAs, the age-match group had significantly higher raw scores than the SLI group on all screening measures ($p<.05$) except Raven's Matrices ($p=.109$), whereas the SLI and language-match groups did not differ significantly on raw score on any of the measures ($p>.05$) except the Raven score ($p=.007$), with the SLI group achieving a higher score.

Table 6.1

Descriptive statistics for screening measures for all groups

		Participant Group					
		SLI		age-match		language-match	
Test	Score	*M*	*SD*	*M*	*SD*	*M*	*SD*
Ravens	Raw	25.69_{a}	5.01	29.31_{a}	3.43	20.23_{b}	4.13
	Standard	102.85	9.93	112.00	11.30	109.00	8.03
GFTA-2	Raw	5.38_{a}	2.22	0.54_{b}	1.66	5.85_{a}	5.11
	Standard	92.23	2.98	103.00	5.54	103.46	5.94
BPVS-II	Raw	66.54_{a}	13.26	102.85_{b}	17.05	66.38_{a}	14.77
	Standard	76.85	9.61	105.85	12.73	105.69	11.07
BPVS-sf	Raw	15.85_{a}	3.56	21.85_{b}	4.16	15.31_{a}	2.75
	Standard	75.15	18.74	104.92	17.78	103.23	9.99
TROG	Raw	11.85_{a}	2.48	17.77_{b}	1.48	12.62_{a}	2.93
	Standard	77.54	7.67	107.92	10.83	101.08	10.73
EVT	Raw	69.62_{a}	10.84	91.77_{b}	18.93	60.00_{a}	9.86
	Standard	81.85	10.80	99.92	14.52	100.85	11.42
Recalling	Raw	17.46_{a}	3.50	43.38_{b}	11.64	20.23_{a}	7.89
Sentences	Scaled	3.23	0.60	8.85	2.41	6.46	2.57
Digit Recall	Raw	25.23_{a}	4.07	30.77_{b}	4.92	24.38_{a}	4.23
	Standard	86.92	16.76	102.77	16.48	98.69	17.61
Artic. Rate	syl/sec	0.20_{ab}	0.04	0.17_{a}	0.03	0.21_{b}	0.03

table continues

Note. Ravens = Coloured Progressive Matrices; GFTA-2 = Goldman-Fristoe Test of Articulation-2; BPVS-II = British Picture Vocabulary Scales 2nd ed.; sf = short form; TROG = Test for Reception of Grammar; EVT = Expressive Vocabulary Test; Standard score, M=100, SD=15; Scaled score, M=10, SD=3; Artic. = Articulation; syl/sec = syllables per second. For raw scores, means in the same row that do not share subscripts differ at p<.01 in the Tukey HSD comparison.

6.1.2: Procedure

The measures reported in the present study were completed in two individual half hour sessions in a quiet room in the child's school. Each child completed two experimental tasks, *serial recall* and *nonword repetition*, and a measure of *articulation rate* in the first session. Order of presentation of the two repetition tasks was counterbalanced, with 6 or 7 participants within each group completing serial recall first, and the remainder, nonword repetition first. The BPVS short form (Dunn et al., 1982) and the *digit recall* subtest of the *Working Memory Test Battery for Children* (WMTB-C; Pickering & Gathercole, 2001) were completed in a second session that followed within one month.

Experimental tasks. Each of the repetition tasks comprised 8 experimental trials preceded by 2 practice trials presented at each of three syllable lengths – 3, 4 and 5 consonant-vowel (CV) syllables. The serial recall and nonword repetition lists were constructed from a pool of phonemes excluding the eight consonants that are late acquired (Shriberg & Kwiatowski, 1994). Only tense vowels were included so that the multisyllabic nonwords were produced with equal stress across syllables (Dollaghan & Campbell, 1998), thereby minimizing prosodic differences across tasks. The resulting pool of 30 CV syllables generated by combining 13 consonants and 8 vowels are shown in Appendix 5. Twenty-four syllables were selected for use in the experimental trials. The remaining six syllables were employed in the practice trials only with the exception of one syllable from the experimental pool that had to be used to construct the five-syllable practice items in order to fulfill the criteria described below for sequence construction. The eight sequences at each list length were created by combining the syllables from the 24-syllable pool for the experimental tasks with the following constraints: no phonemes were repeated within a sequence; all syllables occurred at least once for each list length; each vowel occurred in each ordinal position at least once within each list length; all syllables occurred at least four times in different ordinal positions across all the items.

A digitized recording was made of a female speaker producing syllables in isolation and multisyllabic nonwords. Presentation of the experimental stimuli was controlled by a specialized computer program written in Visual Basic (Microsoft Corporation, 2003). For the serial recall task, the child was asked to listen to each sequence of sounds, and to repeat them in the same order at the end of the sequence. The syllable sequences were presented at the rate of one every 750 ms for serial recall. For nonword repetition, the child was told that they would hear a made-up word and asked to repeat it back immediately. All responses were recorded digitally and phonetically transcribed.

The duration of consonants and vowels (segments) in all syllables, and the total duration for the nonword repetition stimuli were measured on an acoustic waveform with visual and auditory control using the software program, Goldwave (2003). Consonant durations included closure, burst and aspiration, where applicable. Vowels were measured from onset to offset of voicing. For some medial syllables, the point at which the vowel ended and the following consonant began was difficult to determine (i.e., /vəʊyaɪmɔɪ/). No differences were found between the measured durations for these units and the remaining segments in comparable positions ($p>.05$). Table 6.2 presents average total stimuli, and segment durations for the monosyllable nonwords, and initial, medial, and final syllables positions in the multisyllabic forms. Medial positions for the 4- and 5- syllable nonwords comprised the average durations of segments occurring in the 2nd and 3rd syllable positions of 4-syllable sequences, and 2nd, 3rd, and 4th syllables of 5-syllable sequences. Preliminary analyses revealed no differences in consonant or vowel durations at these medial positions ($p>.05$, all cases). In one-way ANOVAs comparing duration across tasks, no significant difference was found for consonants ($p>.05$) whereas vowel durations were significantly longer in the monosyllables for serial recall than the multisyllable nonwords for nonword repetition ($p<.001$). Segment durations in the nonword repetition stimuli were compared in two-way ANOVAs as a function of length (3-, 4-, 5-syllable nonwords) and position (initial, medial, final). No differences were found in consonant durations ($p>.05$) whereas vowel durations were significantly longer in the final positions of the 3-, and 4-syllable sequences ($p<.01$, both cases).

Table 6.2

Mean (SD) consonant (C), vowel (V), and total durations (msec) for stimuli employed in each experimental task

		Syllable Position						Total
		Initial		Medial		Final		Sequence
Task/Length		C	V	C	V	C	V	
Nonword Repetition								
3 syllable	*M*	60	210	90	200	100	340[a]	1201
	SD	30	50	40	50	70	50	2
4 syllable	*M*	70	250	100	220	110	300[a]	1606
	SD	50	30	40	40	40	40	6
5 syllables	*M*	100	250	100	240	100	280	2040
	SD	40	50	50	40	60	60	47
Serial Recall	*M*	80	370[a]					
	SD	40	50					
3 syllables								1950[b]
4 syllables								2700[b]
5 syllables								3450[b]

a – denotes tasks/positions with significantly longer vowels (*p*<.01, all cases)

b – approximate value based on presentation rate of 1.33 syllables/msec

Digit recall. Digit recall is commonly employed to assess short-term memory, and was included in the present study as an additional measure of short-term memory capacity. The digit recall task involved the presentation of a sequence of digits that the child was required to recall in correct serial order. The digit lists were constructed randomly without replacement from the digits ranging from one to nine, and were spoken at a rate of one digit per second. Following three practice trials, a maximum of six lists of digits was presented beginning with two or three digits (depending on success in the practice trials) to a maximum of nine digits. List length was increased by one if the child recalled four lists at that length correctly. If the first four trials were correct, the child was credited with correct recall of all six lists at that length and the next list length commenced. Testing continued until three lists of a particular length were recalled incorrectly. The number of lists correctly recalled is scored, and standard scores calculated based on the published norms (Pickering & Gathercole, 2001).

Articulation rate. A measure of articulation rate was included in the study because articulation rate is known to be related to memory span (Hulme et al., 1984), and children with SLI may have slower articulation rates than typically developing control children (e.g., Scheltinga, van der Leij, & van Beinum, 2003). Each child was asked to repeat each of the following words as fast as possible, five times - *elephant, newspaper, telephone, banana*, and *bicycle*. Following Hulme et al. (1984) and Hulme and Tordoff (1989), these words were selected because they are highly familiar, require rapid alternating movements, and use labial, alveolar, and velar sounds. The digital recordings of each trial were measured on an acoustic waveform with visual and auditory control using the software program, Goldwave (2003). Each run was measured from onset to offset of voicing. A run was defined as at least two repetitions of a target word without pauses of more than 150 msec. Number of syllables per second was calculated for each run, and the mean of all runs was taken as the articulation rate.

6.2: Results

Descriptive statistics for articulation rate and digit recall are provided in Table 6.1. In separate ANOVAs comparing groups on these measures, the main effect of group was significant: articulation rate, $F(2,36)=4.360$, $p<.05$, $\eta_p^2=0.20$; digit recall, $F(2,36)=7.998$, $p<.001$, $\eta_p^2=0.31$. For articulation rate, Bonferroni-adjusted pairwise comparisons indicated that articulation rate was faster for age-match than the language-match group ($p<.05$). None of the remaining pairwise comparisons were significant ($p>.05$, all cases). For the digit recall task, the raw scores of the age-match group were significantly higher than both the SLI and language-match groups ($p<.01$, both cases) whereas the SLI and language-match groups did not differ ($p>.05$).

Recall accuracy in the experimental tasks was scored at the syllable and phoneme level using a strict serial order criterion according to which a unit is only scored as correct if it is recalled in its original position within the sequence. Raw scores were converted to percentage values for the purposes of comparison across sequence lengths. A rationalized arcsine transform function was used to convert all percentage scores into interval level data prior to statistical analysis (Studebaker, 1985).

The percentage of syllables correct for the three participant groups on the serial recall and nonword repetition tasks is summarized in Table 6.3. Repetition accuracy was higher for nonword repetition than serial recall across all groups. The decline in accuracy with increasing sequence length was greater in serial recall than nonword repetition. On all tasks, the SLI group performed at a markedly lower level than the age control group; this difference was greater for nonword repetition than for serial recall. Levels of accuracy were comparable for the SLI and the language-match groups on serial recall, but the SLI group performed at lower levels on nonword repetition for the 3- and 4-syllable sequences.

Table 6.3

Percent syllables and segments correct at each sequence length for each group

		Syllables			Consonants			Vowels		
Length^a →		3	4	5	3	4	5	3	4	5
Group ↓										
					Nonword Repetition					
SLI	*M*	66.67	39.18	21.35	76.28	53.12	39.81	75.32	55.77	43.85
	SD	18.87	22.88	11.66	17.21	20.09	16.05	14.07	19.88	17.19
age-	*M*	88.46	65.62	30.38	94.23	73.08	51.35	90.38	75.00	58.46
match	*SD*	11.56	17.95	10.97	6.49	17.28	10.93	10.81	16.88	16.57
language-	*M*	74.04	49.52	23.08	85.26	61.78	40.97	77.24	59.38	40.96
match	*SD*	19.63	21.83	12.79	14.00	19.27	20.12	18.97	19.93	20.12
					Serial Recall					
SLI	*M*	60.90	25.97	7.12	70.83	40.38	14.81	82.05	53.61	20.58
	SD	17.06	15.17	6.60	13.92	12.46	10.02	12.54	20.37	9.64
age-	*M*	73.72	45.67	20.19	80.13	53.61	33.27	88.46	74.04	39.81
match	*SD*	11.95	21.22	13.63	12.86	20.21	13.52	10.86	17.13	15.83
language-	*M*	61.22	28.37	11.92	69.23	39.90	21.73	88.14	55.53	29.23
match	*SD*	21.14	16.26	13.00	18.82	16.74	12.9	10.46	19.93	20.75

a – length in syllables

An ANOVA was performed for syllables correctly recalled by each child within the three participant groups as a function of task (serial recall and nonword repetition) and length (3, 4, and 5 syllables). All three main effects were significant: task, $F(1,36)=73.241$, $p<.001$, $\eta_p^2=0.67$; length, $F(2,72)=528.185$, $p<.001$, $\eta_p^2=0.94$; group, $F(2,36)=5.980$, $p<.01$, $\eta_p^2=0.25$. All interaction terms were nonsignificant: task and group, $F(2,36)=0.610$, $p>.05$, $\eta_p^2=0.03$; length and group, $F(4,72)=1.282$, $p>.05$, $\eta_p^2=0.07$; task and length, $F(2,72)=0.550$, $p>.05$, $\eta_p^2=0.02$; task, length, and group, $F(4,72)=1.384$, $p>.05$, $\eta_p^2=0.07$. Bonferroni-adjusted pairwise comparisons indicated that the SLI group performed significantly more poorly than the age-match group ($p<.01$), but similarly to the language-match group ($p>.05$). The age-match group also obtained significantly higher scores than the language-match group ($p<.05$). The main effects of task and length reflect, respectively, greater recall accuracy for nonword repetition than serial recall, and poorer recall accuracy with increased length. It should be noted that the pattern of group differences was unchanged in corresponding ANCOVAs with either Raven score or articulation rate entered as covariate.

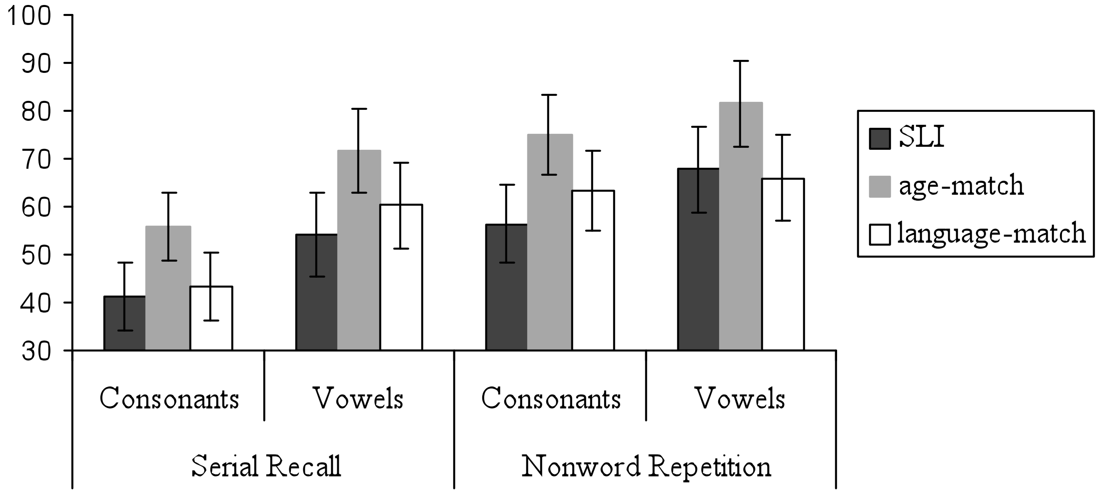
Table 6.3 also presents descriptive statistics for percentage of consonants and vowels correctly recalled by children in each group for both experimental tasks. Repetition accuracy was considerably higher in nonword repetition than serial recall for consonants, and for vowels at the 5-syllable length. For both consonants and vowels, the decline in accuracy with increasing sequence length was greater in serial recall than nonword repetition. The SLI group performed at a markedly lower level than the age-match group, and at levels comparable to the language-match group for both segments. The poorest performance of the

SLI group relative to the language-match group was for consonants in the 3- and 4-syllable nonword repetition sequences, and relative to both control groups for consonants and vowels in the 5-syllable serial recall sequences.

In an ANOVA comparing performance as a function of task, group, length, and segment (consonants, vowels), all four main effects were highly significant: task, $F(1,36)=105.719$, $p<.001$, $\eta_p^2=0.75$, reflecting greater recall accuracy for nonword repetition; segment, $F(1,36)=44.101$, $p<.001$, $\eta_p^2=0.55$, reflecting more accurate repetition of vowels; length, $F(2,72)=553.160$, $p<.001$, $\eta_p^2=0.94$, due to the decline in accuracy with increasing sequence length; and group, $F(2,36)=5.683$, $p<.01$, $\eta_p^2=0.24$, with the age-match group performing at a superior level. There were three significant two-way interactions: task and segment, $F(1,36)=21.629$, $p<.001$, $\eta_p^2=0.36$, due to the greater nonword repetition advantage for consonants; segment and length, $F(2,48)=5.832$, $p<.01$, $\eta_p^2=0.14$, reflecting the greater decrement to consonants with increasing length; and task and length, $F(2,72)=3.413$, $p<.05$, $\eta_p^2=0.09$, due to the greater decline in serial recall accuracy with increasing length. The three-way interaction between task, segment, and group was significant also, $F(2,36)=4.433$, $p<.05$, $\eta_p^2=0.20$. The remaining interactions were nonsignificant: task and group, $F(2,36)=0.165$, $p>.05$, $\eta_p^2=0.009$; segment and group, $F(2,36)=0.165$, $p>.05$, $\eta_p^2=0.009$; length and group, $F(4,72)=0.637$, $p>.05$, $\eta_p^2=0.05$; task, length, and group, $F(4,72)=1.898$, $p>.05$, $\eta_p^2=0.10$; segment, length, and group, $F(4,72)=1.844$, $p<.05$, $\eta_p^2=0.09$; task, segment, and length, $F(2,72)=2.109$, $p>.05$, $\eta_p^2=0.06$; and task, segment, length, and group, $F(4,72)=1.791$, $p>.05$, $\eta_p^2=0.09$. In corresponding ANCOVAs with either Raven score or articulation rate entered as covariate, the pattern of group differences was unchanged.

Figure 6.1 displays the mean recall accuracy for consonants and vowels collapsed across length for each task and group. In order to explore the interaction between task, segment, and group further, separate analyses were completed comparing the SLI with each control group. Results of the ANOVA comparing the SLI and age-match groups confirmed that scores of the age-match group were significantly higher in all conditions (serial recall, $p<.05$ both cases; nonword repetition, $p<.01$, both cases). In the ANOVA comparing the SLI and language-match groups, the interaction between task, segment and group remained significant, $F(1,24)=16.872$, $p<.005$, $\eta_p^2=0.41$. It is apparent from Figure 6.1 that the SLI group recalled vowels less well than the language-match group in serial recall, and consonants less well in nonword repetition.

Figure 6.1. Mean consonant and vowel recall accuracy (and 95% confidence intervals) collapsed across sequence length as a function of task and group

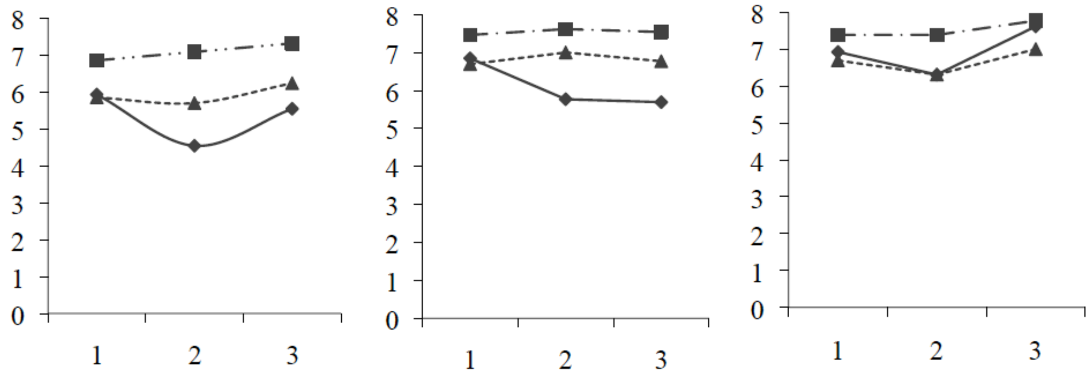


In order to provide a more detailed analysis of the pattern of performance in serial recall and nonword repetition, recall accuracy was examined as a function of serial position across groups. Individual participant scores for each of three serial positions (initial, medial, final) collapsed across length were calculated by separately averaging the number of consonants and vowels recalled either in the initial, all medial (i.e., 2nd syllable of 3-syllable, 2nd, 3rd syllables of 4-syllable, 2nd, 3rd, 4th syllables of 5-syllable lengths), or final position of a sequence, for each experimental task. Mean numbers of correctly produced syllables, consonants, and vowels at each serial position for all sequence lengths and groups are provided for nonword repetition and serial recall in Figures 6.2 and 6.3, respectively.

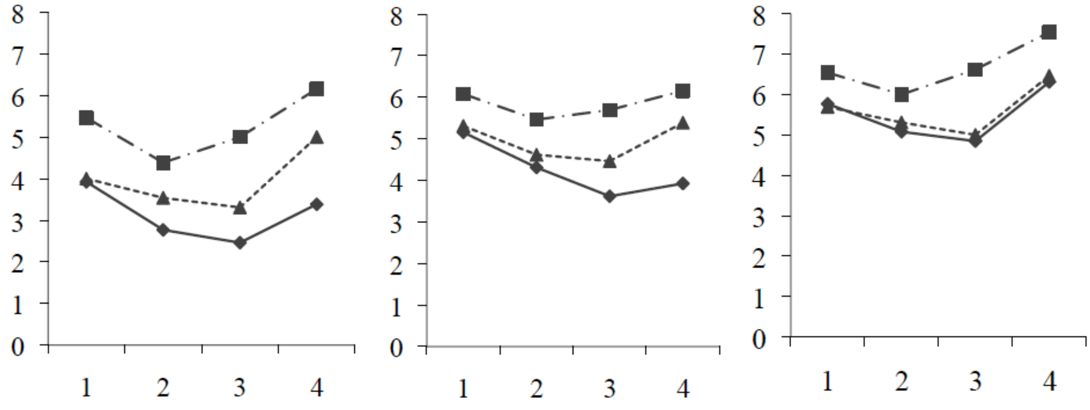
Figure 6.2. Mean correct responses as a function of serial position and group for the repetition of nonwords of (a) 3 syllables, (b) 4 syllables, and (c) 5 syllables.

Syllables Consonants Vowels

(a) 3 syllables



(b) 4 syllables



(c) 5 syllables

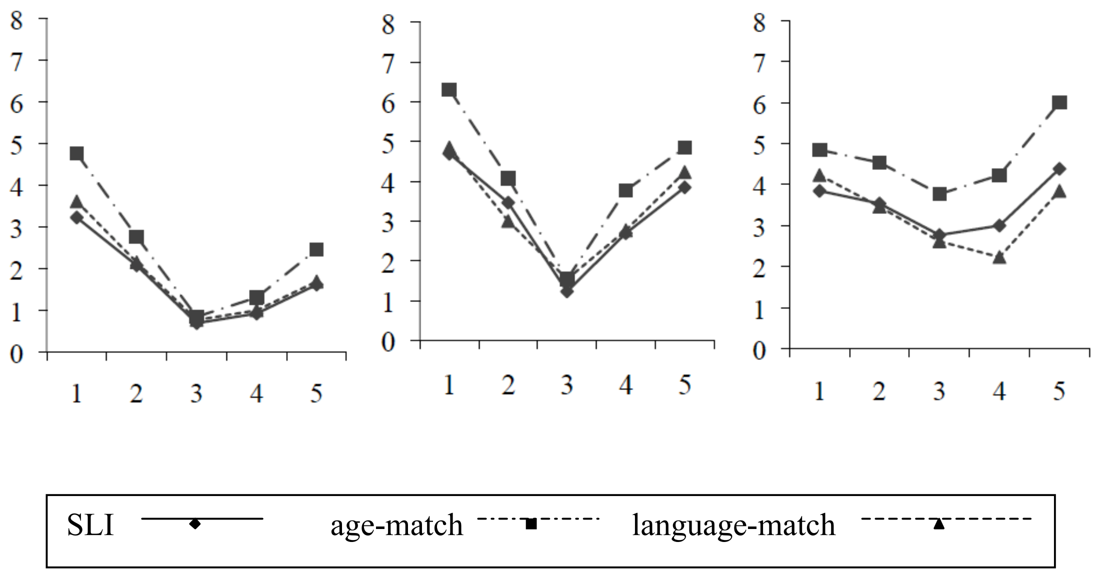
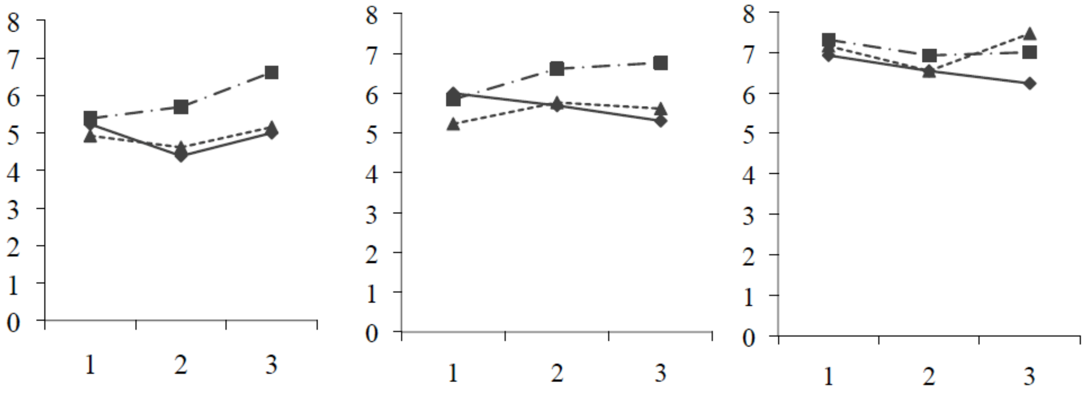


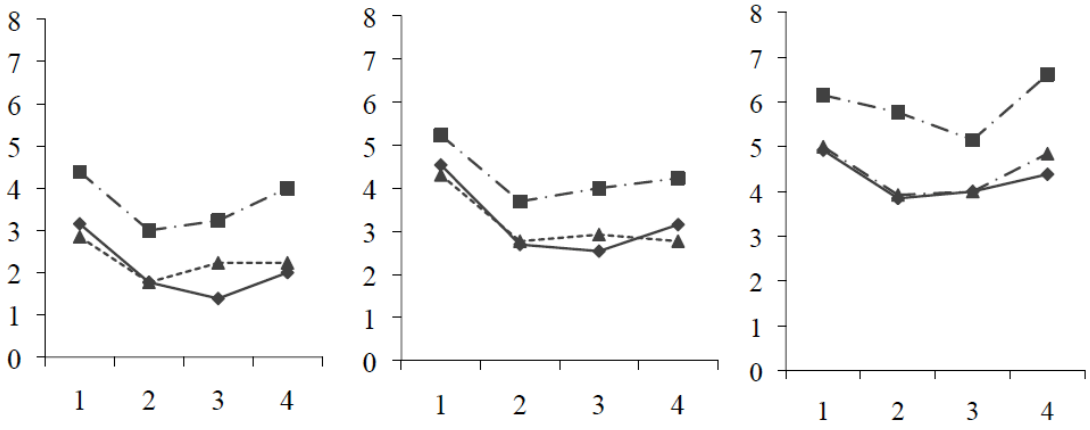
Figure 6.3. Mean correct responses as a function of serial position and group for the serial recall of (a) 3 syllables, (b) 4 syllables, and (c) 5 syllables.

Syllables Consonants Vowels

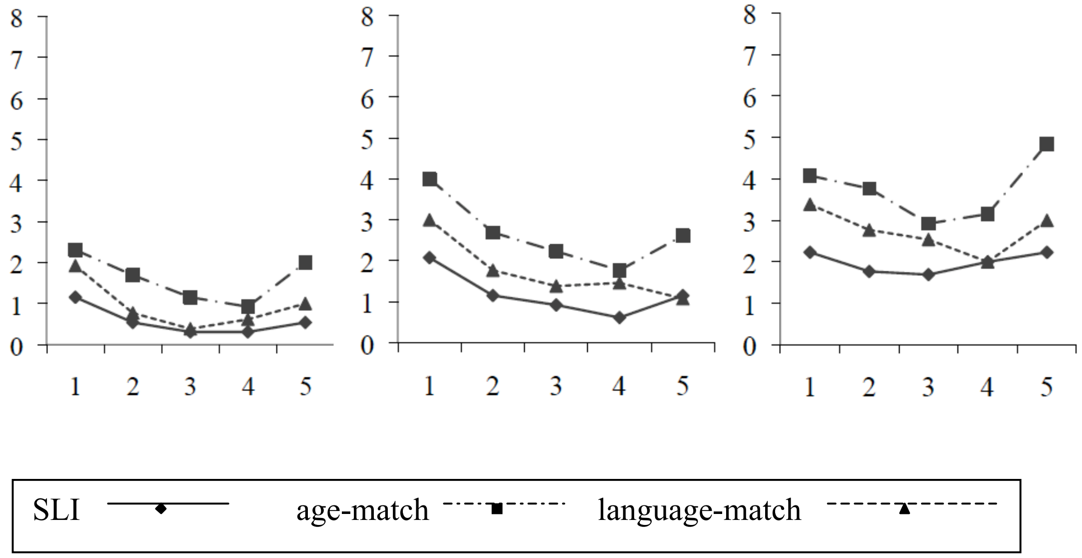
(a) 3 syllables



(b) 4 syllables



(c) 5 syllables



Consider first the syllable level. An ANOVA was performed for syllables correctly recalled as a function of task and position (initial, medial, final). As in the previous analyses, the main effects of task, $F(1,36)=62.051$, $p<.001$, $\eta_p^2=0.63$, and group, $F(2,36)=6.095$, $p<.01$, $\eta_p^2=0.25$ were significant. Also significant were the main effect of position, $F(2,72)=88.125$, $p<.001$, $\eta_p^2=0.71$, and the interaction between task and position, $F(2,72)=6.377$, $p<.05$, $\eta_p^2=0.15$. The remaining terms were nonsignificant: task and group, $F(2,36)=0.441$, $p>.05$, $\eta_p^2=0.02$; position and group, $F(4,72)=1.359$, $p>.05$, $\eta_p^2=0.07$; task, position, and group, $F(4,72)=0.738$, $p>.05$, $\eta_p^2=0.04$. Within-subject contrasts revealed a significant quadratic function for the main effect of position. Pairwise comparisons indicated that medial position scores were significantly lower than initial or final scores ($p<.001$) while initial and final scores did not differ ($p>.05$). These results are consistent with standard primacy and recency effects. Table 6.4 summarizes recall accuracy as a function of serial position and task collapsed across groups. While the superior performance for nonword repetition and the serial position curve for both tasks are clearly evident, the effect of primacy was greater in nonword repetition than serial recall.

Table 6.4

Mean (standard error) recall accuracy for phonemes across serial positions as a function of repetition task

	Serial Position					
	Initial		Medial		Final	
Task	*M*	*SE*	*M*	*SE*	*M*	*SE*
Syllables						
Nonword repetition	4.85	0.22	2.85	0.19	4.38	0.25
Serial recall	3.48	0.19	2.15	0.16	3.17	0.20
Phonemes						
Nonword repetition	5.85	0.16	4.32	0.18	5.85	0.20
Serial recall	4.86	0.16	3.33	0.18	4.41	0.18

A corresponding ANOVA was performed on the phoneme accuracy scores as a function of group, task, segment (consonant, vowel), and serial position. Significant effects that mirrored those of previous analyses included: task, $F(1,36)=106.203$, $p<.001$, $\eta^2_p=0.75$; position, $F(2,72)=128.658$, $p<.001$, $\eta^2_p=0.78$; segment, $F(1,36)=50.142$, $p<.001$, $\eta^2_p=0.58$; group, $F(s,36)=6.021$, $p<.01$, $\eta^2_p=0.25$; task and segment, $F(1,36)=25.966$, $p<.001$, $\eta^2_p=0.42$; task, segment, and group, $F(2,36)=5.437$, $p<.01$, $\eta^2_p=0.23$. Also significant were interactions between segment and position, $F(2,72)=23.365$, $p<.001$, $\eta^2_p=0.39$, and task and position, $F(2,72)=6.919$, $p<.005$, $\eta^2_p=0.16$. Nonsignificant terms included: task and group, $F(2,36)=0.215$, $p>.05$, $\eta^2_p=0.02$; segment and group,

$F(2,36)=0.062$, $p>.05$, $\eta_p^2=0.003$; position and group, $F(4,72)=1.133$, $p>.05$, $\eta_p^2=0.06$; task, position, and group, $F(4,72)=0.896$, $p>.05$, $\eta_p^2=0.02$; segment, position, and group, $F(4,72)=0.965$, $p<.05$, $\eta_p^2=0.05$; task, segment, and position, $F(2,72)=1.545$, $p>.05$, $\eta_p^2=0.04$; and task, segment, length, and group, $F(4,72)=2.297$, $p>.05$, $\eta_p^2=0.11$. The mean and standard error values for the interaction between task and position at the phoneme level are displayed in Table 6.4 along with the syllable data. Scores were higher in nonword repetition than serial recall at all positions ($p<.001$, all cases). The appearance of a more V-shaped function in nonword repetition than serial recall was confirmed in the analysis of simple effects indicating that while recall was significantly less accurate in the final than initial position for serial recall ($p<.01$), performance at these positions did not differ for nonword repetition ($p>.05$). For the interaction between segment and position, scores were significantly higher for vowels than consonants at medial and final positions ($p<.001$, both cases) but equivalent at the initial position ($p>.05$).

To summarize, recall of both syllables and phonemes was more accurate in nonword repetition than serial recall. For phonemes, this advantage was greater for consonants than vowels. While performance decreased with increasing sequence length for both tasks, the impact of length was greater on serial recall and on consonants. Standard primacy and recency effects were noted in both experimental tasks. The primacy portion was more extensive than the recency portion for serial recall as is commonly reported, but these effects were equivalent in nonword repetition (see also, Gupta, 2005). Vowels were recalled more accurately than consonants, an effect that was greater in medial and final sequence positions. The SLI group performed more poorly than the age-match group and at similar levels to the language-match group on both experimental tasks, and an additional measure of short-term memory, digit recall. In contrast to the language-match group, the SLI group recalled vowels less well in serial recall, and consonants less well in nonword repetition. Group differences were unchanged when scores were adjusted either for nonverbal ability or articulation rate.

Error analysis. Errors were classified as omissions, substitutions, additions, or migrations. The first three categories can be considered item errors: An *omission* error was recorded when no phoneme occurred in an expected position. A *substitution* error was recorded when a phoneme not occurring anywhere in the target was provided in place of a target phoneme. An *addition* was noted when an extra unit appeared in the response. A *migration* error occurred whenever a phoneme from the target was recalled in the incorrect position and reflects an order error. For each participant group, frequency and proportions of the four error types for syllables, consonants and vowels are provided in Table 6.5 for nonword repetition and Table 6.6 for serial recall.

Table 6.5

Error patterns in nonword repetition for all participant groups

	Error Types								
	Omissions		Substitutions		Migrations		Additions		Total
Groups	count	prop[a]	count	prop[a]	count	prop[a]	count	prop[a]	count
				Syllables					
SLI	21	0.03	673	0.92	25	0.03	12	0.02	731
age-match	52	0.09	468	0.85	26	0.05	5	0.01	551
language-match	38	0.05	623	0.88	44	0.06	7	0.01	712
Total	111	0.06	1764	0.88	95	0.05	24	0.01	1994
				Consonants					
SLI	98	0.15	247	0.38	267	0.42	30	0.05	642
age-match	29	0.07	145	0.34	245	0.57	9	0.02	428
language-match	94	0.16	218	0.38	245	0.42	23	0.04	580
Total	221	0.13	610	0.37	757	0.46	62	0.04	1650
				Vowels					
SLI	40	0.09	193	0.42	214	0.47	8	0.02	455
age-match	18	0.06	112	0.39	158	0.55	1	0.003	289
language-match	60	0.13	166	0.35	241	0.51	1	0.002	468
Total	118	0.10	471	0.38	613	0.51	10	0.008	1212

a - prop. = proportion

Table 6.6

Error patterns in serial recall for all participant groups

	Error Types								
	Omissions		Substitutions		Migrations		Additions		Total
Groups	count	prop[a]	count	prop[a]	count	prop[a]	count	prop[a]	count
					Syllables				
SLI	80	0.10	663	0.85	33	0.04	5	0.01	781
age-match	21	0.03	563	0.92	21	0.03	5	0.01	610
language-match	100	0.13	577	0.79	52	0.07	4	0.01	733
Total	201	0.09	1803	0.85	106	0.05	14	0.01	2124
					Consonants				
SLI	124	0.16	362	0.46	261	0.33	42	0.05	789
age-match	43	0.07	280	0.48	251	0.43	11	0.02	585
language-match	139	0.18	353	0.47	228	0.30	35	0.05	755
Total	306	0.14	995	0.47	740	0.35	88	0.04	2129
					Vowels				
SLI	84	0.14	222	0.36	304	0.50	3	0.003	613
age-match	21	0.05	159	0.40	217	0.55	21	0.05	397
language-match	100	0.19	152	0.29	279	0.52	1	0.001	532
Total	205	0.13	533	0.35	800	0.52	25	0.02	1542

a - prop. = proportion

Consider first the syllable level. Substitutions were the dominant error type at the syllable level for all groups and conditions. Migration errors of entire syllables were infrequent (5%), although migrations constituted approximately 40% of consonant errors overall and 50% of vowel errors in serial recall. Omissions and additions were rare at the syllable level indicating that recall attempts and input sequences typically matched in number of syllables.

Consonant errors varied according to task with substitutions occurring at rates similar to migration errors in nonword repetition but at higher rates in serial recall. Consonant additions were rare, and will not be analysed further. Omissions were uncommon, and did not occur for a greater proportion of individuals in the age-match than SLI or language groups (31%, 8%, 0%, respectively). As a result, only the substitution and migration errors were included in further analyses. Error proportions were transformed using an arcsine root function in order to make them appropriate for analysis of variance, as categorical data with repeated measures cannot be submitted to a chi-square test (Osbourne, 2002; Hopkins, 2000). An ANOVA was performed on the consonant error proportions as a function of group, task, and error type (substitutions, migrations). There was a significant main effect of group, $F(2,36)=11.217, p<.001, \eta^2_p=0.38$, which was indirectly due to the lower proportion of omission errors in the age-match group resulting in substitution and migration errors representing a larger proportion of errors for this group than either of the other two groups ($p<.001$, both cases). There was a significant interaction between error and group, $F(2,36)=4.214, p<.05, \eta^2_p=0.19$, due to the higher proportion of migration errors in the age-match than either of the other two groups ($p<.01$, both cases). There was no difference in the proportion of substitution errors between groups ($p > .05$, all cases). There was also a significant interaction between task and error, $F(1,36)=39.080$, $p < .001$, $\eta^2_p=0.52$. Analysis of simple effects confirmed that the proportions of substitutions was significantly greater in serial recall than nonword repetition ($p < .001$) whereas the proportion of migrations was significantly greater in nonword repetition than serial recall ($p < .001$). The remaining terms were nonsignificant: task, $F(1,36)=1.103$, $p > .05$, $\eta^2_p=0.03$; error, $F(1,36)=0.265$, $p > .05$, $\eta^2_p=0.01$; task and group, $F(2,36)=0.338$, $p > .05$, $\eta^2_p=0.02$; task, error, and group, $F(2,36)=0.674$, $p > .05$, $\eta^2_p=0.04$.

A corresponding ANOVA performed on the vowel errors as a function of group, task, and error type (substitutions, migrations) revealed a significant main effect of error type, $F(1,36)=23.660$, $p < .001$, $\eta^2_p=0.40$, due to the higher proportion of migration than substitution errors on vowels. The remaining terms were nonsignificant: task, $F(1,36)=2.514$, $p > .05$, $\eta^2_p=0.07$; group, $F(2,36)=1.894$, $p > .05$, $\eta^2_p=0.10$; task and group, $F(2,36)=1.739$, $p > .05$, $\eta^2_p=0.09$; error and group, $F(1,36)=1.845$, $p > .05$, $\eta^2_p=0.09$; task, error, and group, $F(2,36)=0.655$, $p > .05$, $\eta^2_p=0.04$.

Consonant substitution errors were examined further in terms of the relationship between articulatory features of the substituted and input phonemes. Three distinctive articulatory features were considered in this analysis: presence/absence of voicing, place of articulation, and manner of articulation. Substitutions were scored according to the number of different features from the target consonant such that a score of 1 indicated that the substitute and target differed by 1 distinctive feature, 2, two features, and 3, three features. From these, a mean score was calculated for each participant and task. Table 6.7

presents mean numbers of different distinctive features characterizing substitutions for both tasks and all participant groups. Mean differences were similar across groups, but higher in serial recall than nonword repetition. In the ANOVA performed on these data as a function of group and task, the main effect of task was significant, $F(1,36)=6.607$, $p<.05$, $\eta_p^2=0.16$, confirming that the substituted phonemes were more closely related to the target in nonword repetition than serial recall. All remaining terms were nonsignificant: group, $F(2,36)=0.200$, $p>.05$, $\eta_p^2=0.01$; task and group, $F(2,36)=1.162$, $p>.05$, $\eta_p^2=0.06$.

Table 6.7

Mean (SD) number of distinctive features differing between substituted and target consonant phonemes in each repetition task for all participant groups

Task	Participant Groups						Total	
	SLI		age-match		language-match			
	M	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
Serial Recall	2.00	0.19	2.05	0.17	1.98	0.17	2.00	0.17
Nonword Repetition	1.82	0.19	1.77	0.62	1.94	0.18	1.84	0.39

Note: Means reflect number of distinctive features that differ between two phonemes such that lower means indicate more closely related phonemes.

To summarize the error analyses, consonant migrations were more common, and substitutions more closely matched to input phonemes, in nonword repetition than serial recall. The pattern of vowel errors did not as a function of task. A greater proportion of the errors of the age-match group were migrations and a lower proportion omissions, than either the SLI or language-match groups.

6.3: Discussion

In this study, the performances of children with SLI, and typically-developing children were compared on nonword repetition and serial recall tasks in which matched sequences of syllables were presented auditorily for recall. The purpose of the study was to establish whether nonword repetition and serial recall are comparable measures of verbal short-term memory, or are influenced differentially by additional mechanisms. Of particular interest was whether the deficits of the SLI group would be comparable in magnitude in both tasks consistent with the suggestion that the characteristic nonword repetition deficit in SLI is attributable to an impairment of verbal short-term memory (Gathercole & Baddeley, 1990a). In line with findings from many previous studies of short-term memory behaviour, standard primacy and recency effects were present within sequences for both serial recall and nonword repetition. Vowels were recalled more accurately than consonants, and performance declined with increasing sequence length. Importantly, though, nonword repetition was associated with more accurate repetition overall, an advantage that was greater for consonants than vowels, and was less affected by increasing length. Consonant errors were more closely related to the target in nonword repetition whereas vowel errors did not differ across tasks. The SLI group showed very substantial decrements on both paradigms in comparison with age-match control children. While the SLI and language-match groups were indistinguishable when responses were scored at the syllable level, differences were noted at the phoneme level: The SLI group recalled vowels less well in serial recall and consonants less well in nonword repetition. As well, errors made by the SLI group were less closely related to the target than those of the age-match group.

These results add to growing evidence that nonword repetition and serial list recall are related (Gupta, 2003, 2005; Gupta et al., 2003). Decreased recall accuracy for lengthier sequences is typically attributed to temporal decay of the phonological representations in a short-term store (Baddeley, et al., 1975; Cowan, et al., 1991). The bow-shaped serial response curve is widely accepted to reflect the retention of order information (e.g., Page & Norris, 1998). The presence of both of these hallmark findings in the nonword repetition and serial recall tasks in the present study suggests that common mechanisms for retaining item and order are operative in both tasks. One possibility proposed by Gupta (2004) is that a nonword is processed like a list when first encountered, and is thus directly dependent on list sequencing mechanisms.

Recall in nonword repetition and serial recall was not equivalent in the present study, however: multisyllablic forms were reproduced more accurately than matched syllable sequences presented singly in a list. It is apparent that additional mechanisms facilitated recall in nonword repetition. Of potential importance are the temporal differences that distinguish the two paradigms. Overall sequence duration was shorter in nonword repetition than in serial recall allowing an earlier response, and so perhaps reducing opportunities for decay of the phonological representation in the short-term store. One problem for this suggestion, however, concerns the phoneme level data. Recall accuracy in nonword repetition was improved to a greater extent for consonants than vowels even though it was vowel duration that was significantly shorter in this paradigm (and consonant duration unchanged).

Another possible explanation of the superior nonword repetition performance is that participants capitalized on the physical cues to underlying structure that were present in the connected multisyllabic nonwords but not the isolated individual syllables. Such cues include prosody (Roy & Chiat, 2004) and coarticulation (Nijland, et al., 2002), both of which play important roles in the perception and retention of speech. In English, there are a small number of places of articulation for consonants, which tends to promote coarticulation whereas tense vowels tend to resist coarticulation. Thus, coarticulatory cues may be expected to have had the greatest impact on consonants in the present study. Consistent with this suggestion, the nonword repetition advantage was greater for consonants than vowels, and consonant errors were more closely related to the target in nonword repetition than serial recall. Although the present study aimed to minimize prosodic differences across tasks, it may be also that recall was facilitated more by the '(non)word' level contour which spanned the entire sequence in nonword repetition rather than each list item in serial recall.

Similarly, the group differences in the present results cannot be entirely explained by the presence of an impairment of verbal short-term memory in the SLI group. Phoneme recall was differentially impaired across tasks: Relative to much younger children matched for language abilities, the SLI group recalled consonants less well in nonword repetition and vowels in serial recall. These findings do not appear to be readily accommodated by problems in the SLI group with rapidly changing stimuli (Tallal & Piercy, 1973a, b; Tallal, et al.,

1981) as the difficulties occurred across segments of equal length (consonants), and for segments of longer duration (vowels in serial recall). One possibility that could account for the problem with consonants in nonword repetition in the present study relates to the previous discussion regarding coarticulation: Children with SLI may be less sensitive to the additional information available in the acoustic signal of naturally-spoken nonwords. Consistent with the results of the study reported in chapter 4, it may be too that the SLI group was disadvantaged by the significant additional demands on both the planning and execution of speech-motor gestures imposed by the repetition of multisyllabic nonwords relative to a sequence of simple syllable forms (Vance et al., 2005), which may be expected to have had a greater impact on consonant production. It is also possible that the SLI group was differentially impaired by the greater overall duration of the serial recall sequences, resulting in less accurate vowel retention.

The present findings extend those reported for immediate recall of unfamiliar sequences for typically developing groups (Gathercole et al., 1999; Gathercole et al., 2001; Jefferies et al., 2006; Treiman & Danis, 1988). In contrast to studies employing closed lists of familiar items (Aaronson, 1968; Bjork & Healy, 1974), item errors were more common than order errors at the whole-syllable level replicating previous findings with open stimulus sets composed of both words and nonwords (Gathercole et al., 1999; Jefferies et al., 2006; Treiman & Danis, 1988). At the phoneme level, order errors have been found to be more common than item errors in list recall (Gathercole et al., 2001; Treiman & Danis, 1988). Although in the current work this was true in serial recall for vowel errors only, it was also the case for consonant errors in nonword repetition. It is clear from these findings that independent migrations of phonemes are a common feature of both serial recall and nonword repetition, although the degree to which phonemes remain tightly bound in a coherent unit may be influenced by lexical and semantic knowledge as recently demonstrated by Jefferies et al. (2006). These results call for a verbal short-term memory model in which order information is associated with individual phonemes rather than a singular representation of an item.

The results of the present study indicate that while verbal short-term memory constrains both nonword repetition and serial recall performance, additional cues inherent in nonword repetition do lead to more accurate recall with greater retention of features of target phonemes. This pattern established for two age groups of typically developing children in the current work appears to be a signature of normal development. The cues available in multisyllabic nonword repetition may allow for richer encoding with greater binding of phonemic features resulting in better quality phonological representations that are less susceptible to interference or loss. Children with SLI were markedly impaired on all of the measures tapping verbal short-term memory included in the present study, but their pattern of phoneme retention differed relative to children with similar language abilities. Nonword repetition differs from serial recall in several ways such as the presence of prosodic and coarticulatory cues, temporal properties, and motoric demands. Systematic experimental examination of the influences of these factors on the deficits in SLI has the potential not only to illuminate core problems underlying this developmental learning disorder, but also to inform the development of programs of remediation and learning support to boost language learning abilities in affected children.

Chapter 7

General Discussion

This final chapter reviews the main findings presented in this thesis. The implications of the findings for understanding the cognitive processes underlying Specific Language Impairment (SLI), and the nature of short-term and working memory deficits in SLI are discussed. Section 7.1 discusses immediate memory in SLI. Section 7.2 examines the nature of working memory deficits in SLI. Section 7.3 considers the conjunction between verbal short-term memory and generalized processing deficits in SLI, including implications for theories of SLI and working memory. Section 7.4 examines the specific case of nonword repetition and its relation to SLI. The practical implications of the findings are discussed in section 7.5. Finally, in section 7.6 the main theoretical implications are summarised and final conclusions formed.

7.1: Immediate Memory in SLI

This thesis considers short-term and working memory in SLI. Short-term memory involves the brief retention of information. Chapter 1 reviewed evidence that short-term memory for verbal or phonological information plays an important role in vocabulary learning. The findings reviewed in section 1.3.1 suggested that verbal short-term memory supports the learning of novel phonological forms during the early stages of language learning, but not the learning of associated semantic knowledge (Gathercole, in press; Gathercole et al., 1997). As reviewed in section 1.4.1, much of the support for a verbal short-term memory deficit in SLI comes from studies of nonword repetition (e.g., Conti-Ramsden et al., 2001; Dollaghan & Campbell, 1998; Edwards & Lahey, 1998; Ellis Weismer et al., 2000). It has been suggested, however, that nonword repetition taps skills in addition to verbal short-term memory such as lexical knowledge (Snowling et al., 1991) and phonological awareness (Bowey, 2001). Very few studies have employed more conventional measures to assess verbal short-term memory in SLI such as serial recall of words or digits (e.g., Conti-Ramsden, 2003b; Graham, 1980; Hick et al., 2005). One goal of study 1 was to provide a detailed assessment of verbal short-term memory in a group of school-age children with SLI using conventional measures standardized for this age. A second goal was to compare the verbal short-term memory deficit as identified by these conventional measures to the impairment observed on a measure of nonword repetition commonly employed in research studies of SLI groups.

Visuospatial short-term memory appears to play a relatively minor role in language learning (Adams et al., 1999; also see, section 1.3.2), although it may support language in contexts specifically tapping visual or spatial skills such as words or text with spatial connotations (DeBeni, et al., 2005; Pazzaglia & Cornoldi, 1999; Phillips, et al., 2004). There have been no recent studies of visuospatial short-term memory in children with SLI using conventional measures, and an additional goal of study 1 was to provide this.

As described in detail in section 1.2.2, working memory subsumes short-term memory incorporating both the current processing and temporary storage activities associated with a particular cognitive activity. The evidence reviewed in section 1.3.3 links working memory with a variety of language abilities such as following directions (Engle, et al., 1991), and vocabulary learning in context (Daneman & Green, 1986). Several studies have reported substantial working memory deficits in children with SLI (Ellis Weismer et al., 1999; Hoffman & Gillam, 2004; Montgomery, 2000a, b). None of these studies, however, have examined both short-term and working memory in the same group of children with SLI. One of the main goals of study 1 was to compare profiles of short-term and working memory in a single sample of children with SLI using multiple standardized measures that could provide a robust composite estimate of each construct.

7.1.1: Summary of findings

Study 1 established verbal short-term memory deficits in a group of 20 school-age children with SLI that exceeded their delay in language development. Standard scores of at least 1 *SD* below the mean on the verbal short-term memory measures characterized 70% of the group, a rate of incidence that was five times greater than that of a typically developing sample. Deficits on the Children's Test of Nonword Repetition (CNRep; Gathercole & Baddeley, 1996) were substantially larger with all individuals tested scoring more than 4 *SD* below the standardized mean. These findings contrasted markedly with the age-appropriate performance of the group on the phonological awareness measures.

The performance of this group of children with SLI on the visuospatial measures was within the low average range. Although considerable individual variability was observed, scores were appropriate for the children's language ages.

Substantial impairments in working memory were established for 95% of the group, and were significantly greater in magnitude than the language impairment that formed the basis of the SLI diagnosis. This profile was 9 times less likely to occur in a typically developing sample.

7.1.2: Implications of findings

The results of study 1 provided direct evidence of substantial deficits in both verbal short-term and working memory in a single sample of children with SLI. The results provide further support for reports of verbal short-term memory impairments as reflected by poor nonword repetition in SLI (e.g., Gathercole & Baddeley, 1990a; Montgomery, 1995a) by establishing deficits across several different verbal storage measures. A comparative overview of previous findings has intimated that SLI groups may perform substantially more poorly on nonword repetition than conventional measures of verbal short-term memory (e.g., Conti-Ramsden, 2003b; Dollaghan & Campbell, 1998; Gathercole & Baddeley, 1990a; Kirchner & Klatzky, 1985; van der Lely & Howard, 1993). The results of study 1 do indeed bear this out: The standardized scores of the SLI group were considerably lower for nonword repetition than for the serial recall paradigms. These results suggest that nonword repetition may be tapping additional cognitive processes that are also impaired in SLI. One suggestion has been that phonological awareness skills may influence nonword repetition (Bowey, 2001). The relative strength in phonological awareness in the present SLI group, however, suggests that this was not the factor instrumental in the poor nonword repetition in study 1.

The finding of relatively preserved visuospatial and markedly impaired verbal short-term memory in a single SLI sample establishes that the difficulty retaining information for brief periods of time in SLI disproportionately affects the verbal domain. This result is entirely consistent with the evidence reviewed in section 1.2.1 regarding domain-specificity in short-term memory, and the multiple-resource working memory model of Baddeley and Hitch (1974) described in section 1.2.2.

The finding of working memory impairments in the children with SLI reinforces previous reports of deficits in verbal complex memory span in SLI (Ellis Weismer et al., 1999; Montgomery, 2000a, b). The deficits were more marked and pervasive for working memory than verbal short-term memory indicating that the poor performance of the SLI group on the complex memory measures did not simply arise due to poor short-term storage, but instead reflected the contribution of working memory to task performance. The findings point to dual deficits in SLI in both verbal short-term memory and working memory.

7.2: Working Memory in SLI

The central executive within working memory is conceived of as a domain-general resource responsible for the processing or manipulation of information during cognitive tasks (Baddeley, 1996). A domain-general factor has been found both to contribute to complex memory span performance, and be highly related to general intelligence and scholastic achievement (e.g., Bayliss, et al., 2003; Engle, Tuholski, et al., 1999). As reviewed in section 1.2.2.1, however, other findings have raised the possibility that processing resources within working memory may be fractionated into distinct verbal and visuospatial components (e.g., Jurden, 1995; Morrell & Park, 1993; Shah & Miyake, 1996). The studies that have reported working memory deficits in children with SLI have largely employed verbally based measures (e.g., Ellis Weismer, et al., 1999; Montgomery, 2004). Only one study has compared SLI and age-matched groups on a complex memory measure that was wholly spatial in nature (Bavin et al., 2005), and no group differences were found. In contrast, children with SLI have been found to perform more poorly or more slowly than typically developing children on processing tasks that tap nonlinguistic abilities such as hypothesis testing (e.g., Ellis Weismer, 1991) and mental rotation (Johnston & Ellis Weismer, 1983). On this basis, it has been argued that a general processing deficit underlies SLI. The main goal of study 2 was to provide an assessment of visuospatial working memory skills in the same group of children with SLI who participated in study 1 and for whom substantial deficits of both verbal short-term and verbal working memory were established in order to investigate whether the working memory impairments characterizing the group extended across domains.

7.2.1: Summary of findings

Study 2 included one measure of visuospatial short-term memory and three measures of visuospatial working memory. The children with SLI performed at comparable levels to same-age peers on all measures, and more highly on one measure than a younger control group matched for language abilities. These findings contrasted markedly with the large and consistent impairments of verbal short-term and working memory exhibited by the children in the SLI group and reported in study 1.

7.2.2: Implication of findings

The results of study 2 suggest that the immediate memory deficits in SLI primarily involve the verbal domain. The data appear inconsistent with a general processing account of SLI (e.g., Bishop, 1992; Johnston, 1994; Ellis Weismer, 1996): The marked impairments on verbal short-term and verbal complex memory tasks in study 1 and age-appropriate performance on visuospatial working memory tasks in the same individuals with SLI in study 2 appear to rule out explanations in terms of domain-general mechanisms. The findings also appear to represent a substantial challenge to the view of processing resources within working memory as domain-general by providing evidence of domain-specific fractionation.

Nevertheless, one further possibility remains. The complex memory paradigms employed in studies 1 and 2 represent the ends of a continuum from wholly verbal tasks to wholly visuospatial tasks. It is possible that a general processing deficit exists in SLI, but does not always lead to impaired performance. For example, adequate performance levels may be maintained in a complex memory task even in cases of slower processing if the storage portion is not taxing. Consistent with this notion, accounts of SLI as a deficit in processing speed (Kail, 1994) or capacity (e.g., Bishop, 1992; Johnston, 1994) both assume a disproportionate impact on the linguistic domain due either to the more time sensitive nature of verbal information (Miller et al., 2001) or the number of processing components inherent in linguistic tasks (e.g., Leonard, 1989; Leonard et al., 1991).

7.3: Slow Processing Plus Verbal Storage Deficit in SLI

The findings of study 1 and 2 suggested that children with SLI are impaired in short-term and working memory tasks tapping the verbal domain. The extent to which SLI is characterized by domain-specific deficits is a matter of considerable interest because this issue differentiates several of the theoretical accounts of SLI reviewed in section 1.5. The goal of study 3 was to provide a systematic investigation of the precise source of the verbal working memory impairment in SLI, by measuring each of the potential factors separately and in combination, across the verbal and visuospatial domains.

A further aim of the study was to provide a strong test of possible domain-specific working memory deficits suggested by the results of studies 1 and 2 for children with SLI, as well as other studies (e.g., Shah & Miyake, 1996). According to the Baddeley and Hitch (1974) working memory model and in contrast to the findings of studies 1 and 2, processing resources are conceptualized as domain-general. However, one limitation of the working memory assessments administered in studies 1 and 2 is that they represented either verbal storage and verbal processing or visuospatial storage and visuospatial processing. Bayliss et al. (2003) examined constraints on complex memory span performance in children and adults by varying the nature of the task components systematically across the verbal and visuospatial domains. Results showed that performance on the complex span tasks was independently constrained by both domain-general processing efficiency and domain-specific storage capacity. Study 3 employed the paradigm developed by Bayliss et al. to systematically assess the domain-specificity of storage and processing deficits in SLI.

7.3.1: Summary of findings

The results of study 3 were clear. Children with SLI were impaired on the verbal but not visuospatial storage tasks when compared to same-age peers indicating a verbal short-term memory impairment. As well, the SLI group was slower to respond than the age-matched group in both the verbal and visuospatial processing tasks reflecting a domain-general processing deficit. Most importantly, though, the SLI group had lower scores even relative to the younger control group matched for language abilities on the complex memory tasks involving verbal storage regardless of processing domain, and these deficits could not be accounted for by differences in either processing speed or verbal storage. Thus, the children with SLI experienced disproportionate difficulties with tasks that involved combining verbal storage with a concurrent processing load.

7.3.2: Implications of findings

The findings of study 3 are both consistent with and extend previous work. SLI deficits were found in speed of processing both verbal and visuospatial information, and also in verbal short-term storage. Taken separately, these deficits are consistent with reports of generalized slowing (e.g., Kail, 1994; Miller et al., 2001) and impaired verbal short-term memory in SLI (e.g., Gathercole & Baddeley, 1990a). But it was the combination of requirements to both store verbal material and process information regardless of domain that had such a drastic impact on the SLI group. It was suggested that a ‘slow processing plus verbal storage’ perspective accommodates much of the current evidence pertaining to both the general processing and verbal short-term memory accounts of SLI, and provides a mechanism for the disproportionate difficulty learning language experienced by children with SLI in the context of a generalized deficit. Children are faced with the need to process all types of information almost constantly. If remembering verbal or phonological information is particularly vulnerable during processing, then long-term acquisition of phonological material may be delayed and/or processing of associated information key to the application of the material may be deficient.

The finding of a domain-general processing impairment is entirely consistent with the multiple-resource working memory model (Baddeley & Hitch, 1974), and the findings of the Bayliss et al. study (2003). Consistent also with the results of studies 1 and 2, the generalized processing deficit demonstrated in study 3 for children with SLI only led to performance decrements on complex memory tasks additionally tapping impaired verbal (as in study 1) but not preserved visuospatial storage (as in study 2).

7.4: Nonword Repetition, Short-term Memory, and SLI

Nonword repetition has been suggested to be a relatively pure measure of verbal short-term memory because of the reduced availability of long-term lexical knowledge to support the unfamiliar phonological forms (Gathercole & Baddeley, 1989; 1993). Recent evidence, however, suggests that nonword repetition and more conventional measures of short-term memory such as digit span tap both shared and distinct processes (Gathercole et al., 1997; see also, study 1). Chapter 5 discussed several factors that have been suggested to influence nonword repetition including lexical knowledge (Snowling, et al., 1991), phonotactic composition of the language (Vitevitch & Luce, 2005), and speech output processes (Wells, 1995).

Nonword repetition deficits are of particular interest in the case of SLI. Chapter 5 reviewed the highly consistent findings of marked and pervasive deficits in nonword repetition in SLI groups (e.g., Botting & Conti-Ramsden, 2001; Dollaghan & Campbell, 1998; Ellis Weismer et al., 2000). The nonword repetition deficit in SLI has a strong genetic basis, and has been linked with abnormalities of chromosome 16q (SLI Consortium, 2002; 2004). It has been hailed both as a phenotypic marker (Bishop et al., 1996) and clinical marker of the disorder (Conti-Ramsden, 2003b). These findings have led to wide spread interest in understanding the nature of nonword repetition deficits in SLI. One suggestion has been that a verbal short-term memory deficit accounts for the impaired abilities of children with SLI to repeat nonwords (Gathercole & Baddeley, 1990a). The main goal of study 4 was to consider if the pattern of poor nonword repetition on two commonly employed measures by an SLI group was consistent with a verbal short-term memory account.

Chapter 6 considered the specific case of nonword repetition and serial list recall. While these tasks are clearly similar, they also differ in some aspects such as coarticulatory and prosodic cues, temporal features, and motoric demands. Study 5 aimed to evaluate the proposal that nonword repetition is an index of short-term memory by comparing nonword repetition and serial list recall for matched phonological sequences with equivalent memory loads. A second goal was to examine whether the deficits of the SLI group would be comparable in magnitude in both tasks as would be predicted if an impairment of verbal short-term memory represents the primary constraint on performance.

7. 4.1: Summary of findings

Consistent with the findings of study 1, study 4 provided evidence that the nonword repetition deficit of the SLI group could not be accounted for solely by an impairment of verbal short-term memory. While poor performance was found for the SLI group relative to same-age peers on both measures employed in the study, significant differences between the SLI group and younger, control children matched for language abilities were found only for the task that relied to a lesser extent solely on verbal short-term memory, the Children's Test of Nonword Repetition (CNRep; Gathercole & Baddeley, 1996). The CNRep differs from the Nonword Repetition Test (NRT; Dollaghan & Campbell, 1998) in important ways; it includes some longer items, and items with recognizable lexical or sublexical units, consonant clusters and later developing phonemes. The poorer relative scores of the SLI group on the CNRep indicate that each of these differences may have influenced performance. *Post hoc* analyses revealed significant differences between the SLI and both control groups for the longer nonwords across tests, and the items of the CNRep containing consonant clusters.

In study 5, all groups repeated multisyllabic nonwords more accurately than equivalent lists of single syllable nonwords. The children with SLI, while markedly impaired on both nonword repetition and serial recall differed in their pattern of phoneme retention relative to children with similar language abilities. The results indicated that while verbal short-term memory constrains both nonword repetition and serial recall performance, additional cues inherent in nonword repetition do lead to more accurate recall with greater retention of features of target phonemes. It was suggested that cues available in multisyllabic phonological forms may result in more accurate encoding or retention. Possible explanations for the differences exhibited by the SLI group included reduced sensitivity to coarticulatory cues in nonword repetition, and greater decrements to performance over the longer retention intervals of serial recall.

7.4.2: Implications of findings

The results of studies 4 and 5 indicate that while verbal short-term memory does play a role in nonword repetition, other factors also contribute to and facilitate performance in this task. They further suggest that children with SLI may be impaired in these other areas as well. The poorer recall of children with SLI than expected for their age on all of the nonword repetition measures and serial recall tasks in studies 1, 4 and 5 as well as many other studies (e.g., Kirchner & Klatzky, 1985; Edwards & Lahey, 1998) provide strong evidence of a verbal short-term memory deficit in SLI. As well, the significant impairment on longer items for recall suggested to reflect temporal decay of the phonological representations in a short-term store (Baddeley, et al., 1975; Cowan, et al., 1991) is consistent with a verbal short-term memory account.

The SLI deficits were not comparable in magnitude across short-term memory tasks, however: the SLI group was impaired to a greater extent on more familiar nonwords associated with increased motoric demands, and differed in the pattern of phoneme retention for nonwords presented either as multisyllabic forms or in single syllable lists. These results open avenues for further research particularly aimed at the unique nature of nonword repetition:

Perhaps children with SLI are less efficient at making use of the prosodic and coarticulatory cues inherent in the multisyllabic productions. It may be also that children with SLI are more disadvantaged in meeting the motoric demands of nonword repetition.

7.5: Practical Implications

The children with SLI in the present studies exhibited a 'slow processing plus verbal storage deficit'. Such a finding may have important practical implications. Children are faced with the task of storing and manipulating information frequently throughout the day (Gathercole et al., 2005). Learning support strategies specific to working memory impairments have been described by Gathercole and Alloway (in press), and hinge on the balance of storage and processing demands. Two principles of intervention for working memory deficits in SLI follow from this storage-processing framework. First, storage of new verbal or phonological information is effortful and resource-demanding for children with SLI. When storage demands are high, processing demands should be minimized. Activities of this nature occur when the child has to store a considerable amount of material that may be arbitrary in structure (such as a series of numbers, or the precise wording of a fairly lengthy sentence). Second, processing of complex instructions is effortful and resource-demanding. When processing demands are high, storage demands should be minimized. Activities of this nature occur when the child has to store material while engaged in another activity that is demanding for them (such as spelling or reading a new word, or making an arithmetic calculation).

From these principles, several learning support strategies can be developed. Many of the strategies for poor working memory function overlap with those commonly employed for language impairment, and form the basis for many ‘best practices’ in teaching. Broadly speaking, two approaches may be considered with respect to the storage of information. First, recognise the storage demands of new or arbitrary information. When introducing information of this nature, the emphasis should be on storing (or learning) the information, rather than on manipulation or processing of the information. Strategies that will facilitate the transfer of the information to long-term memory in a ‘quality-rich’ state should be adopted. Information from word learning studies indicates that children with SLI learn words when presentations are frequent and appropriately spaced: Specifically, the initial introduction of new information should include several repetitions of the key words in order to reduce the risk of decay or interference in the phonological short-term store, followed by a succession of widely spaced booster sessions (Riches et al., 2005). Activities that heighten the awareness of the phonological structure of a word such as counting syllables or listing rhyming words, known to many as phonological awareness activities, will improve the quality of the phonological representation gaining access to long-term memory. In addition, pairing new information with rich contextual information such as hands-on manipulatives or picture stories will facilitate a detailed and complex semantic and syntactic network for the new information once part of long-term memory.

The second approach to managing storage demands is useful when processing demands are inherent to the learning opportunity and cannot be minimized. In these cases, storage demands must be minimized either by using information that is so familiar or automatized as to make storage demands minimal or by providing external aids that make it unnecessary to store the information. Research has shown that when highly familiar information is used in complex working memory span tasks, the familiar information places such a minimal storage demand on the system, that individual variation in the performance is dependent on the variation in processing (e.g., Baddeley, Logie, Nimmo-Smith, Brereton, 1985; Daneman & Carpenter, 1980). Hence, the use of familiar information imposing minimal storage demands such as familiar vocabulary, spellings, or maths, in processing tasks such as formulating sentences, or solving word problems in maths, may allow the child to meet the demands of the processing task and succeed in the lesson. Alternatively, the storage demands for information that is not familiar may be sufficiently minimized as to allow the child to concentrate on the processing task in hand. Such strategies would include listing key information in words or pictures, or using number lines or counting blocks.

Approaches analogous to those described above for storage demands may facilitate success with processing tasks as well. Firstly, effort should be made to minimize processing demands. It must be recognized that many children with SLI in mainstream classrooms do not have the linguistic skills necessary to be able to manage many of the complex processing tasks assigned to them everyday including comprehension of complex, multi-step instructions, or answering questions about a story. In these cases, the processing demands must be minimized by reducing the complexity of the task, either by simplifying vocabulary (common vs lower frequency words), syntactic complexity (simple subject-verb-object constructions rather than relative clauses), or length (single step vs multi-step instructions). Alternatively, providing external aids that assist the child to remember the demands of the task may reduce processing demands. Such strategies may include writing out the key steps in a task, setting up complex tasks as part of a classroom routine that is repeated each day, and identifying a person in the classroom of whom the child may request repetitions or explanations of the information.

7.6: Conclusions

The studies in this thesis provided a thorough and systematic evaluation of short-term and working memory impairments in children with Specific Language Impairment (SLI). Results revealed specific SLI deficits in speed of processing both verbal and visuospatial information, as well as verbal storage consistent with many previous reports of generalized slowing (e.g., Miller et al., 2001) and impairments in verbal short-term memory (e.g., Gathercole & Baddeley, 1990a; Montgomery, 1995a). More than this, though, the findings highlighted the combined impact of these dual deficits with drastic decrements in performance of the children with SLI even relative to younger children with similar language abilities when required to store verbal material while engaged in concurrent processing activities. It is suggested that a ‘slow processing plus verbal storage deficit’ may be expected to pose a specific hindrance to language learning accompanied by generalized impairments as is evident in many children with SLI. Crucial to this account is to demonstrate that this profile is unique to children with SLI. Further research is needed to replicate these findings, and compare working memory profiles of different disorder groups.

The studies also demonstrated that the nonword repetition deficit in SLI cannot be solely accounted for by poor verbal short-term memory. The accumulated evidence pertaining to nonword repetition in SLI indicates that it is a pervasive and consistent deficit, heritable and having a genetic basis, and a potential clinical marker. As such, an important area for future research is to understand the nature of this deficit more fully. The findings of the studies in this thesis point to factors additional to short-term memory that may contribute to nonword repetition such as prosodic information, coarticulatory cues, and speech output demands. A systematic evaluation of the processes underlying nonword repetition that differentiate SLI and typically developing groups is needed.

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Appendix 1. Items from the CNRep (Gathercole & Baddeley, 1996).

dopelate
glistering
pennel
defermication
contramponist
hampent
reutterpation
perplisteronk
blonterstapping
sepretennial
detratapillic
glistow
frescovent
bannifer
stopograttic
woogalamic
ballop
confrantually
fenneriser
altupatory
pristoractional
underbrantuand
trumpetine
sladding
commeecitate
tafflest
loddernapish
barrazon
commerine
empliforvent
thickery
voltularity
versatrationist
rubid
brasterer
diller
penneriful
bannow
prindle
skiticult

Appendix 2. NRT items from Dollaghan and Campbell (1998).

nɑɪb	teɪvɑk	tʃinɔɪtɑʊb	veitɑtʃɑɪdɔɪp
voʊp	tʃoʊvæg	nɑɪtʃoʊveɪb	dævoʊnɔɪtʃig
tɑʊdʒ	vætʃɑɪp	dɔɪtɑʊvæb	nɑɪtʃɔɪtɑʊvub
dɔɪf	nɔɪtɑʊf	teɪvɔɪtʃɑɪg	tævɑtʃinɑɪg

Appendix 3. Nonwords from CNRep in each wordlikeness set with wordlikeness ratings.

Low wordlike set		High wordlike set	
lɒdə'neɪpɪʃ	1.1	'hampənt	2.7
wʊgə'læmɪk	1.6	'sladɪŋ	2.7
'skɪtɪkʊlt	1.7	vɜsə'treɪʃanɪst	2.8
'tæfləst	1.8	'bərəzən	2.9
ditrəta'pɪlɪk	2.0	'glɪstərɪŋ	3.0
'brastərə	2.1	fɛnə'raɪzə	3.0
empli' fɔvənt	2.2	'kəm'isəteɪt	3.2
'dɪlə	2.3	sɛprə'tɛnɪʊl	3.3
'glɪstəʊ	2.3	kən'frantʃulɪ	3.4
prɪstər' akʃənl̩	2.3	'pɛnl̩	3.4
'baləp	2.4	'trʊmpətin	3.4
pən'ɛrɪfl̩	2.4	stɒpə'gratɪk	3.5
riʌtə'peɪʃn	2.4	'rubɪd	3.8
altʃu'peɪtəri	2.5	difɜmɪ'keɪʃn	3.9

Appendix 4. Subsets of CNRep items in each articulatory complexity group.

Length	High Complexity	Low Complexity
2 syllables	'hampənt	'pɛnl̩
	'glɪstəʊ	'baləp
	'sladɪŋ	'rubɪd
	'tæfləst	'dɪlə
	'prɪndl̩	'banəʊ
3 syllables	'glɪstərɪŋ	'dɒpəleɪt
	'frɛskəvɛnt	'banɪfə
	'trʊmpətin	'barəzən
	'skɪtɪkʊlt	'kɒmərin
	'brastərə	'θɪkərɪ
4 syllables	'kəntrɑmpənɪst	wʊgə'læmɪk
	pɜ'plɪstəroɲk	fɛnə'raɪzə
	'blɒntə'steɪpɪŋ	'kəm'isəteɪt
	stɒpə'gratɪk	lɒdə'neɪpɪʃ
	empli' fɔvənt	pən'ɛrɪfl̩

Appendix 5. Syllables used to construct stimuli in both repetition conditions.

Practise trials

/faʊ/ /dZaʊ/ /gɑ/ /vɑ/ /tʃaɪ/ /wɔɪ/ /vəʊ/

Experimental trials

/kaɪ/ /kəʊ/ /daʊ/ /pɔɪ/ /teɪ/ /bɑ/ /gi/ /ku/

/faɪ/ /vəʊ/ /maʊ/ /mɔɪ/ /veɪ/ /tɑ/ /tʃi/ /fu/

/yaɪ/ /tʃəʊ/ /taʊ/ /dɔɪ/ /tʃeɪ/ /dɑ/ /yi/ /vu/