BEYOND STORAGE: WORKING MEMORY
AND SPECIFIC LANGUAGE IMPAIRMENT

by

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B.A. (Hon.), The University of British Columbia, 1997

A THESIS SUBMITTED IN PARTIAL FULFILMENT OF
THE REQUIREMENTS FOR THE DEGREE OF
MASTER OF SCIENCE
in
THE FACULTY OF GRADUATE STUDIES
(School of Audiology and Speech Sciences)

We accept this thesis as conforming
to the required standard

THE UNIVERSITY OF BRITISH COLUMBIA
August 2003

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Date Aug 12, 03
Abstract

This study examined the auditory-verbal and visual-spatial working memory of children with Specific Language Impairment (SLI). In particular, the ability of 12 children with SLI (age 7-11 years) to coordinate storage and processing demands and manage information from different modalities was compared to that of a group of peers with normal language development. All children completed 6 working memory tasks. Two tasks tapped auditory-verbal working memory; children repeated auditorally presented words (storage) in the first task, then categorized the words by size of the referent before recall (storage + processing) in the second task. Two similar tasks in the visual-spatial domain required children to recall location of objects in a 4 x 4 grid (storage) or remember the locations and categorize the objects (storage + processing). Children with SLI had a reduced auditory-verbal working memory capacity relative to their peers, particularly when processing demands were high. In contrast, there was no group difference in the visual-spatial domain. Finally, two dual working memory tasks required children to remember words and locations, thereby managing information from two domains simultaneously. The children with SLI achieved lower span levels than their peers when information from the two domains was presented in an integrated way that required formation of a single mental representation. Performance in the working memory tasks was also related to narrative production as a means of explaining language use.

The results of this project have implications that inform our understanding of SLI. Although the SLI children in this study evidenced a deficit that was localized to the auditory-verbal domain, the findings are not necessarily evidence for a specific
processing deficit account of SLI. Memory strategies and temporal processing in
children with SLI warrant further investigation. The results also inform our
understanding of working memory. Across all tasks, the importance of using complex
measures of working memory to uncover group differences and predict language skills
surfaced. The usefulness of the construct of the central executive was questioned,
because it is unclear how it could support processing differentially across domains.
Further investigation of how working memory, measured independently from language,
can predict language use is warranted.
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Acknowledgements

I would like to thank Dr. Judith Johnston, my thesis supervisor, for her continuous encouragement, support, insight and guidance during the past 3 years. You have helped me to a final product that I did not think possible and of which I am extremely proud.

Dr. Jeff Small and Barb Purves, my committee members, have provided me with excellent suggestions and rushed to meet my tight deadlines. Thank you!

In Salmon Arm, thank you to Jo Nussbaum, SLP and all the staff and students at the schools I visited. Jo has been the perfect role model for the clinician I hope to be some day, and has gone out of her way to help organize testing. All the children who participated were keen and excited; and teachers were flexible and supportive to facilitate testing. A huge hug and thank you is also extended to Sunni and Gary for feeding me, encouraging me, and providing a place to stay during my many visits to Salmon Arm.

Lorraine Reggin, thank you for laying the groundwork for my research and supporting me through the process. Paola Colozzo has been a great colleague, from our initial discussions about ideas for research, through to the testing of subjects, and checking of data. Good luck in your research, and thank you for ensuring I was thorough in all I did!

Saskia and Kat, thank you for your word wizardry and help in improving my writing skills. You gave me the confidence I needed to jump over the last major hurdles.

Finally, to my classmates, friends, and family, for believing in me, supporting me, and encouraging me to stay sane and healthy throughout the last 3 years!
Review of the Literature

1.1 Why Study Working Memory?

The apparent dissociation between language and cognition in children with specific language impairment (SLI) continues to mystify both researchers and clinicians. Language and cognition are argued to be independent, yet it has been postulated that deficits in working memory, one aspect of cognition, underlie SLI (e.g. Montgomery, 2000a, 2000b, 2002; Ellis Weismer, Evans & Hesketh, 1999). Limited research in the influence of working memory on language learning and complex theoretical working memory frameworks have resulted in only partial understanding of the role of working memory deficits and SLI.

Baddeley's (1986) model of working memory will be the framework used to explore the current understanding of the structure and function of working memory. The role of working memory will then be further explored in children with SLI. Their ability to process, integrate and coordinate information from different domains will be experimentally investigated along with the possible correlations between working memory and narrative production. Results of this study will be presented in terms of how they inform current models of working memory, further our understanding of SLI, and provide practical clinical implications for delivering effective intervention for children with language impairments.

In this chapter, the Baddeley (1986) model of working memory will be reviewed as a platform for further discussion of working memory. Then, some current issues within working memory will be examined, followed by an integrated discussion of
working memory and language impairment. Finally, I will present the research questions, and frame the current research investigating working memory in children with SLI.

1.2 Baddeley's Model of Working Memory

1.2.1 Evolution of Baddeley's model

The term working memory is used differently in different domains of research. Within the field of cognitive psychology, working memory as Baddeley (2000, p. 418) defines it refers to a “limited capacity system allowing the temporary storage and manipulation of information necessary for such complex tasks as comprehension, learning and reasoning.” This is the interpretation of working memory that will underlie the current study.

Baddeley and Hitch (1974) evolved the first model of working memory from Atkinson and Schiffrin's (1971) work in short-term memory. Atkinson and Schiffrin suggested that a group of control processes managed the flow of information within memory. The control processes, which included rehearsal, coding, imaging and strategy choice, were suggested to be controlled consciously. Baddeley (1986) used the idea of control processes to delineate his three-component model of working memory. Baddeley's model differed in two keys ways from the earlier short-term memory models. First, it considered memory to consist of multiple components, and secondly it considered the function of working memory to be part of a complex cognitive system. Since the original Baddeley and Hitch (1974) model, Baddeley has published extensively to specify the model more completely and explain new research findings (e.g. Baddeley, 1986;
Baddeley 1996; Baddeley, 1998; Baddeley, 2000; Baddeley, 2002; Baddeley & Hitch, 1994).

1.2.2 Original architecture of Baddeley’s model

According to Baddeley’s (1986) model, working memory comprises of three components: the central executive, the phonological loop, and the visual-spatial sketchpad (See Figure 1). The latter two are considered “slave systems” that are specialized in storage of information. Verbal material is stored in the phonological loop; visual and spatial information is contained within the visual-spatial sketchpad. The nature of the phonological loop has been studied extensively (e.g. Dollahan & Campbell, 1998; Baddeley, Gathercole, & Papagno, 1998; Gathercole & Pickering, 1999) and is now the most clearly understood (Baddeley, 1996). The visual-spatial sketchpad has also received attention in recent years (e.g. Logie, 1995; Pickering, 2001; Pickering, Gathercole & Peaker, 1998; Duff & Logie, 1999), though the specific functions it accounts for remain unclear (Duff & Logie, 1999).

The least studied component of Baddeley’s model is the central executive. Baddeley (1996) suggests that research investigating the functioning of this component is both important and timely. As the central executive has received little attention, the roles and functions remain poorly understood and continue to challenge researchers (Baddeley, 1996). The current study will add to the small but growing body of research that explores the role and structure of the central executive (e.g. Reggin, 2002; Emerson, Miyake, & Rettinger, 1999; Towse & Houston-Price, 2001a, Baddeley, Chincotta & Adlam, 2001). The internal architecture and functional role of each of the 3 components of Baddeley’s model are discussed below.
1.2.3 Phonological loop

The phonological loop is responsible for the storage of verbal information (Baddeley, 1992). This slave system comprises of two separate components (Baddeley, 1986): the phonological store and the articulatory control process. The phonological store holds acoustic or speech-based information for a very brief amount of time (1 to 2 seconds). The articulatory control process uses subvocal repetition to maintain information within the phonological store and concurrently convert visually presented information into the phonological store (Baddeley & Hitch, 1994; Baddeley, 1992).

Although the articulatory control is labelled a ‘process’, the role of the loop is limited to the storage of information. It is important to distinguish this ‘process’ from others that will later be attributed to the central executive.

In addition to understanding the architecture of the proposed phonological loop, the functional role it plays must also be considered (Baddeley, & Hitch, 1994). Several possibilities have been explored, one of which suggests the involvement of the
phonological loop in language comprehension. Research into this relationship is inconclusive (Baddeley & Hitch, 1994). Wilson and Baddeley (1993) report severe comprehension deficits in subjects with phonological loop deficits; however, other studies have shown that subjects with impairments in short-term phonological memory do not have significant language comprehension difficulties (Vallar & Shallice, 1990) and are able to produce spontaneous speech with little difficulty (Shallice & Butterworth, 1977).

Baddeley et al. (1998) propose that the functional role of the phonological loop is language learning (or more specifically word learning) rather than language comprehension. They argue that typical verbal span tasks which require short-term retention of familiar words do not measure the key role of the phonological loop, but instead measure a by-product of its primary function. Retention of familiar words measures long-term memory and storage. Baddeley et al. (1998) suggest that non-word repetition is a better measure of phonological loop function. Gathercole and Baddeley (1990a) compared the abilities of 5-year-old children with either high or low non-word repetition ability to learn phonologically familiar (e.g. Thomas) and unfamiliar (e.g. Pimas) names. The researchers found that neither group found the task of learning familiar names to be difficult, though children with low non-word repetition scores were significantly poorer at learning the phonologically unfamiliar names than those with high non-word repetition scores. Adams and Gathercole (2000) provide further experimental evidence for the argument that the phonological loop is involved in language learning by connecting non-word repetition scores to length of utterances, diversity of vocabulary and a range of syntactic constructions. Despite the plausibility of a connection between
phonological loop capacity and language learning the nature of this link is not immediately transparent. Adams and Willis (2001) present an overview of this link by suggesting that constructing robust long-term phonological forms is necessary to successfully acquire higher forms of language, including lexical items and morphosyntactic structures.

The phonological loop’s suggested role in language learning is consistent with a framework of automaticity. A significant expenditure of resources is required to learn new words, but once a word is well learned, processing is automatic and requires minimal resources. Differences in language processing would be most apparent during the resource demanding learning process.

The phonological loop component of Baddeley’s model thus provides an important contribution to the storage of phonological information and in language learning. It is one of the two slave systems in the working memory model. The second slave system, similar in nature to the phonological loop, but storing information from a different modality, is the visual-spatial sketchpad.

1.2.4 Visual-spatial sketchpad

Baddeley and Hitch (1974) propose that the second slave system, the visual-spatial sketchpad (VSSP), is responsible for remembering and manipulating visual-spatial information such as shape, color and movement. Like the phonological loop, the primary role of this component of working memory is storage, under the control of the central executive. Logie (1986) conducted a series of experiments in which subjects learned a series of words using either subvocal rehearsal or a visual-imagery mnemonic. These tasks were completed either alone, or together with a secondary visual task (pattern
matching), or verbal task (word repetition). He found that the secondary visual, but not verbal, task interfered with the primary visual-imagery task. This is interpreted as evidence for separate resource pools for storage of verbal and visual information. Research to further explore the architecture of the VSSP has lagged behind that of the phonological loop (Logie, 1995), and is still endeavouring to find a division corresponding to the phonological store and articulatory control processes believed to exist within the phonological loop. Logie (1995) proposes a division that included a visual ‘cache’ to store information and an ‘inner scribe’ to process spatial information. Again the term ‘processing’ used to describe the inner scribe is misleading, and is not to be confused with the processing tasks attributed to the central executive.

The functional role of the VSSP remains less clear than that of the phonological loop. According to Baddeley and Hitch (1994) there has been no systematic investigation to explore this issue, thus evidence of function remains inconclusive. Functions which have been suggested include planning and executing spatial tasks, tracking changes in the visual perceptual world over time, and maintaining orientation in space (Baddeley & Hitch, 1994). Future research may bring insight to the question of whether one component could serve such a variety of roles. For the purposes of the current study it is sufficient to consider the VSSP as a storage bin for visual-spatial information.

There are two tasks that have traditionally been used to assess VSSP capacity: Corsi blocks (De Renzi & Nichelli, 1975; as cited in Gathercole & Pickering, 2000) and visual pattern span (Wilson, Scott, & Power, 1987; as cited in Gathercole & Pickering, 2000). These tasks are thought to separately measure two divisions within the VSSP (dynamic processing and static capacity). Dynamic processing is measured with the
Corsi blocks tasks (Pickering et al., 2001). A visual-spatial sequence is presented by tapping randomly on a set of 9 blocks and subjects recall the tapping order. The number of taps increases in length to provide a measure of span performance. This task measures dynamic spatial processing. Static capacity is measured by the visual pattern span task. A series of matrices of squares, some of which are filled, are presented and participants must recall the abstract pattern created by the filled squares. The number of filled squares increases until a participant’s span is reached. This task relies more heavily on the visual storage ‘cache’ (static capacity) (Pickering, Gathercole, Hall, & Lloyd, 2001).

Although examining storage capacity is not one of the central themes of the current study, it is impossible to consider processing capacity without first considering storage. In Baddeley’s multi-component model, which includes separate storage bins for information from different modalities, it is theoretically possible that a dissociation could exist between an individual’s ability to store auditory-verbal and his/her ability to store visual-spatial information. One child could thus be able to easily remember visual-spatial information, such as where an object was hidden in a room, but struggle with auditory-verbal information, such as remembering a phone number. This possibility will be examined within a clinical population known to show an apparent dissociation between language and cognitive skills, children with SLI.

1.2.5 **Central executive**

The final component of Baddeley’s original model of working memory is the central executive. The current study will focus on further exploring the role of the central executive, so a more thorough discussion of this component is warranted. Baddeley
(1996) suggests that the central executive is the most important component of the working memory system in terms of its impact on cognition.

Early versions of the Baddeley model provided little insight into the precise role of the central executive. In the original Baddeley and Hitch (1974) model, the central executive was described as controlling the resources of the two slave systems. In this interpretation, the demands on the central executive depended on the memory load. When memory load was low, little demand was placed on the central executive. When load increased, such that capacity within the modality specific storage slave systems (phonological loop and visual-spatial sketchpad) was exceeded, the central executive devoted resources to storage. Later, Baddeley (1986) suggests that the central executive was also responsible for attentional control. Finally, in 1996, Baddeley delineates the exact roles of the central executive. He recommends trying to systematically separate and explore each of the functions performed by the central executive. Using this approach, he suggests four potential central executive functions: coordinating the two slave systems, attention focusing, attention switching, and interfacing with long term memory.

Parkin (1998) provides a representative criticism of the central executive as presented by Baddeley (1986, 1994). He claims that its role is defined by default; that is any task that cannot be successfully explained by one of the two slave systems is attributed to the central executive. Although researchers (e.g. Stuss et al., 2002) have found an anatomical correlate responsible for attentional processes (dorso lateral prefrontal cortex), Parkin (1998) claims no evidence from either deficit lesion studies or neuroimaging exists to identify one area of the brain that is able to carry out all the roles
potentially attributed to the central executive. In this critique, the central executive was compared to a 'homunculus', a little man with unlimited power, but little explanatory value.

1.2.5.1 Coordinating information from different modalities

The first of the roles for the central executive investigated by Baddeley was the coordinating of information from the two slave systems (verbal and visual modalities). People with dementia of the Alzheimer's type (DAT) were observed to have impairments across working memory, although verbal and visual-spatial storage remained relatively preserved (Baddeley, 1996). Baddeley and colleagues (Baddeley, Logie, Bressi, Della Sala, & Spinnler, 1986) hypothesize that this performance could be due to a deficit in controlling the information coming from the different modalities. A dual task paradigm was used to measure central executive function. In this paradigm, patients were required to perform a visual tracking task in combination with three different tasks: articulatory suppression, reaction to a tone, and digit span. It was hypothesized that the central executive played an important role in coordinating the two slave systems to perform tasks simultaneously. The group with DAT were compared to control groups of younger and older adults. In both the tracking/tone reaction and tracking/digit span combination tasks, members of the DAT group showed a sharper decline in scores than either control group, even though each person was working at his individual span on each of the single tasks. Baddeley et al. (1986) argue that this showed a specific central executive deficit in people with DAT.

Recent research (e.g. Yee, Hunt, & Pellegrino, 1991; Emerson et al., 1999) further deconstructed this dual task role. A difference was described between coordinating
unrelated information from different modalities and integrating information from different modalities into a single representation. Emerson et al. (1999) conducted research exploring the individual differences in ability to integrate and coordinate information. An integration task was designed which required participants to verify auditory information while integrating related knowledge from a visual display. Coordination was measured by having participants verify auditorally presented information that was unrelated to the visual display. Each of these dual tasks was completed twice. Participants also completed both the visual-spatial and verbal tasks separately in a single task paradigm. Reaction time and accuracy of response was compared across the integrating and coordinating tasks.

A multiple regression analysis was used to assess the hypothesis that once the effects of single task performance were regressed out, any leftover variance would be systematically related to an ability to integrate and coordinate information. This is indeed what Emerson et al. (1999) found; leftover variance was significantly correlated both between the two different presentations of each dual task, and between the integrated and coordinated tasks. Two important conclusions result from this study. First, the systematic leftover variance provides evidence for the existence of a central executive that requires resources to combine information from different modalities. Secondly, the significant correlation between the integrated and coordinated tasks suggests that these tasks are related and may both be attributed to the central executive.

1.2.5.2 Attentional control

A further two central executive roles focus on attention, attention switching and attention focusing. The attentional roles of the central executive described by Baddeley
link working memory to theories of attention. The primary focus of research into the responsibility of attention in working memory has been to examine the effects of attentional control in ageing. These functions are not delineated clearly in this model, nor are they the focus of the current study. I will, however, return briefly to the issue of attention in the discussion of issues within working memory later in this chapter.

1.2.5.3 Interface with long term memory

The final function of the central executive that Baddeley (1996) identifies is in the interfacing of working memory with long-term memory. Baddeley has recently elaborated on this function, namely in modifying his model to include a new slave system, the episodic buffer (Baddeley, 2000). In this new version of the model, Baddeley (2000) no longer attributes interface with long-term memory as an executive control function. Instead, he creates a new component, the episodic buffer, to temporarily store information from long-term memory while it is interfacing with current working memory. This new episodic buffer is similar to the other slave systems in that it is assumed to be a limited capacity storage system under the control of the central executive. The buffer is assumed to be an interface between episodic long-term memory and the central executive, storing information in a multi-modal way that is integrated across space and time.

The addition of the episodic buffer resulted from experimental evidence that the original model could not explain. For example, it was found that visual similarity impacts span for verbal material, indicating that verbal and visual-spatial information are somehow combined (Baddeley, 2000). A second example is the concept of chunking. Chunking allows an adult to remember 16 or more words when words are presented in a
sentence. When recalling unrelated words, an adult is generally only able to recall 5 or 6. The common explanation is that sentence recall is assisted by additional information from long-term memory. The original Baddeley model provided no working space for this process given that the central executive was not meant to function as a storage bin.

The addition of the episodic buffer is part of the process of delineating the function of the central executive. Baddeley (1996) proposed that one of the roles of the central executive was the temporary storage of items from long-term memory; however, the addition of the episodic buffer removes this as a central executive role. This is one step towards further understanding the functions of the central executive.

1.2.6 Summary of Baddeley’s model

In summary, Baddeley’s model (Baddeley & Hitch, 1974; Baddeley, 1986) traditionally viewed working memory as a three-component system, consisting of 2 slave systems for storing information from the verbal and visual-spatial modalities that are controlled by a central executive. A third slave system, the episodic buffer, was added following research aimed at better understanding the central executive. While Baddeley’s model has contributed greatly to our understanding of working memory, it is not without critics, primarily focusing on two general themes: the neat modularity and the vague definition of the central executive (e.g. Parkin, 1998). This model raises important issues in working memory, some of which have been explored by other models. The following section will incorporate evidence from other prominent models of working memory to explore 4 unresolved issues within working memory: 1) Can working memory capacity be separated by modality? 2) How do the demands of storage and processing
interact? 3) Does the central executive exist? 4) What is the relationship between working memory and language?

1.3 Outstanding Issues in Working Memory

Baddeley's model is one of at least three prominent models in the field of working memory. Despite the number of theoretical models, many aspects of working memory remain poorly understood. The following section outlines 4 outstanding issues in the field with evidence from different theoretical viewpoints.

1.3.1 Can working memory capacity be separated by modality?

Baddeley (1986) describes a modular system, where auditory-verbal information is stored separately from visual-spatial information. These two components are contrasted to the central executive, which performs processing functions across both modalities. This modular viewpoint is not shared by others in the field.

Baddeley (1986) does not claim that anatomical correlates of the phonological loop or the VSSP exist, instead these slave systems are functionally defined. Research by Logie, Zucco and Baddeley (1990) provides an illustrative example of the functional evidence to support the separation of visual-spatial and auditory-verbal storage. In this study, participants remembered visual-matrix patterns (visual-spatial storage task) or letter sequences (auditory-verbal task). Each of these tasks was combined with another task that required manipulation of either visual-spatial or mathematical material. The researchers found that the manipulation of visual-spatial information created more interference on the memory of visual-matrix patterns than it did on the memory of letter sequences. Manipulation of mathematical material had the opposite result; performance
on the letter sequence task declined more than performance on the visual-matrix patterns task. Baddeley (1986) suggests this double dissociation, which has been frequently replicated in the literature (e.g. Brooks, 1967; Smyth & Scholey, 1996), is evidence for separate storage capacities.

Just and Carpenter (1992) propose a ‘limited capacity’ theory, in which components are separated according to storage or processing functions, not modality. There is some modularity within this system; however architectural boundaries are not inherent in the model. Instead boundaries are created when there are insufficient resources available to support the interaction between processes. Their original model is limited in scope, referring only to working memory for language; however they suggest that the theory could be extended to other cognitive domains including processing of higher visual information.

Shah and Miyake (1996) investigate whether the proposed limited pool of resources could also serve storage and processing functions in spatial tasks. They administered a typical reading span task to a group of college students, who answered simple questions about sentences (processing) and then remembered the final word of each sentence (storage). Participants also completed a spatial task that required both processing and storage. In the spatial task subjects saw a series of letters presented in normal or mirror-imaged form, rotated in varying degrees around a center point. They were asked to identify whether each letter was normal or mirror-imaged (processing) and then, following the final letter, recall where the top of each letter had appeared on the screen (storage). Using this paradigm, Shah and Miyake (1996) found that the task tapping verbal processing and storage correlated only with verbal ability measures and
the task tapping spatial processing and storage correlated only with spatial ability measures (e.g. Minnesota Paper Form Board Test, Space Relations Test). These findings support the use of working memory tasks to predict complex cognitive abilities in domains outside language. Similar to Baddeley’s findings, these findings also suggest that limited resources are modality specific.

Evidence from both Baddeley’s (1986) and Just and Carpenter’s (1992) perspectives suggests a separation of resources to support working memory in different modalities. MacDonald and Christiansen (2002) present a contrasting view of working memory. They postulate that working memory capacity does not exist independently from the representation of knowledge. This perspective does not incorporate any modularity within the system. Thus, the entire notion of modularity has been questioned. Even if one assumes modularity, there are still many more questions. For example, are resources supporting processing also modality specific? How is the limited capacity divided? Baddeley (1986) divides the capacity by modality, with different slave systems supporting information from different modalities. Just and Carpenter (1992) divide total capacity by separating processing and storage functions. Waters and Caplan (1996) suggest an alternative, delineating the modules according to whether processing is conscious or automatic. These questions about the modularity of working memory remain controversial in the literature. The current study will investigate storage and processing in the auditory-verbal and visual-spatial domains to inform the question of modularity in working memory.
1.3.2 How do the demands of storage and processing interact?

In all versions of the Baddeley model (Baddeley & Hitch, 1974; Baddeley 1986, 1996), the distinction has remained between storage tasks (performed by the slave systems) and processing tasks (performed by the central executive). In one exception to this clear separation of functions, Baddeley (1986) suggests that when the capacity of a slave system is reached, the central executive may be recruited to perform storage tasks. An issue that remains unclear in the field of working memory is how the demands of storage and processing interact within a limited capacity system.

The trade-off between storage and processing is implicit in the Baddeley model; however Just and Carpenter (1992) provide a more explicit discussion of this issue. Their model posits a limited resource pool that is divided between storage and processing, such that a trade-off exists between storage and processing. When processing demands increase, there are fewer resources available for storage and vice versa. When this trade-off favors allocation of resources to processing, it may lead to ‘forgetting’ of previously stored information. However, when this trade-off favors storage, and resources are de-allocated from processing, this can lead to a slow-down in processing (Miyake, Carpenter, & Just, 1994).

Evidence for the importance of considering both storage and processing together comes from the work of Daneman and Carpenter (1980). Responding to earlier findings that word and digit span measures (storage only) did not correlate with comprehension, they devised a complex span task that required both processing and storage of information. In this reading span task, adult subjects were asked to read a series of sentences (processing demands) and then recall the last word of each sentence (storage
demands). Span was defined as the maximum number of sentence final words a subject could remember while still reading aloud (processing) the sentences. A common variation of this task requires subjects to listen to the sentences and make true / false judgements (processing) before repeating the final word in each sentence (storage). In their initial study, Daneman and Carpenter (1980) found that scores on both the reading and listening span tasks correlated highly with both verbal SAT scores and specific tests of comprehension.

Towse and Houston-Price (2001b) caution against using a processing-storage trade-off model to constrain our thinking of memory. No task can be defined purely as a storage task or a processing task. It is automatic to try to make sense of and process incoming information. Towse, Hitch and Hutton (1998) question the entire notion of a processing-storage tradeoff, based on their research findings indicating that temporal factors are more important in predicting working memory skills than processing / storage trade-offs. They conducted a series of experiments where span tasks were performed under different temporal conditions. Although there was no change to the amount of processing or number of items to be stored, results varied significantly depending on how long an item needed to be stored. Following from this data, Towse et al. (1998) suggest that the interpretation of span tasks is not a simple processing storage trade-off, and temporal factors must also be considered. Extra time may allow additional rehearsal or processing of stored information. Clearly both processing and storage are important in measuring working memory capacity; however, exactly how storage and processing interact, and how they relate to central executive functioning remains unclear.
1.3.3 Does the central executive exist?

The third issue in working memory questions the existence of the central executive. Although the central executive is central to Baddeley’s (1986) model, Baddeley himself admits that it is poorly understood (1998). A ragbag of tasks including allocating attention and integrating information are ascribed to the central executive. Baddeley states that the central executive does not have an anatomical location (1998), but is still a useful concept to describe working memory performance. Does it make sense to unify these control systems under one concept of a central executive? By doing so, we may gain convenience, but at the same time there is a danger of losing the essence of what we are studying. In the face of criticism (e.g. Parkin, 1998), Baddeley is attempting to more clearly delineate exactly what roles the central executive might play (Baddeley, 1996; 1998).

No other model of working memory includes a construct similar to the central executive. How do other models handle these processes attributed to Baddeley’s central executive? One area commonly attributed to the central executive is attentional control. Just and Carpenter’s model (1992) was derived from theories of attention, and discusses attention in the context of allocation of resources when demand exceeds capacity. Their model outlines potential options. Is storage favored over processing? Are processes that are less demanding of resources and more automatic favored over those that are more demanding? Although the model does not yet provide answers to this question, this model asks different questions about the nature of higher-level processes than Baddeley’s model. In the complex task of understanding the central executive, it is important to investigate how other models talk about complex cognition, even if they do not postulate...
a body like the central executive. Thus far, there is no experimental evidence to link the different roles attributed to the central executive. First, research must clearly define what these roles are, and then we can face the challenge of deciding whether this is a useful grouping.

1.3.4 What is the relationship between working memory and language?

The final issue of working memory relevant to the current study is the connection between working memory and language. Baddeley has explored this relationship only in the role the phonological loop plays in language learning (Gathercole & Baddeley, 1990a, Baddeley et al., 1998). These researchers suggest that although phonological loop capacity does not correlate with linguistic performance in adults, it might be important in developing robust phonological representations, thereby increasing efficiency of processing in children. Baddeley’s model has provided some insight into the relationship between working memory and language learning, but has not systematically explored how working memory relates to language use.

The connection between working memory and language use is central to the Just and Carpenter (1992) model. This limited capacity model originated from the findings that short-term theories of memory are unable to account for individual differences in speed and accuracy of language comprehension. Just and Carpenter claim that although storage differences cannot predict language comprehension skills, individual differences in total capacity (storage + processing) can account for this variation. They posit two possible sources of individual variation in working memory to explain why one person might have better language comprehension skills than another: total capacity or processing efficiency. In a total capacity approach, one individual would possess more
total resource capacity than another. In a processing efficiency approach, total resource capacity might be the same, however one individual would use that capacity more efficiently. Although acknowledging these two possible differences, Just and Carpenter suggest they are mutually compatible. This question, of the difference between total capacity and processing efficiency extends beyond the limits of the specific model and should be central to our thinking about working memory in any framework.

A contrasting view of the relationship between working memory and language emerges from the connectionist model of MacDonald and Christiansen (2002). They suggest that working memory does not exist independently of language. Instead processing capacity results from network architecture and experience. Repeated exposure to a certain language forms increases the strength of this connection, thereby facilitating processing. This model questions the whole notion of working memory as an independent construct.

Daneman and Merkle (1996) provide strong evidence to support Just and Carpenter’s (1992) claim that measures tapping both processing and storage are good predictors of language comprehension. Their meta-analysis of 77 studies using complex span tasks suggests that measures requiring both storage and processing are more likely to predict language comprehension than those that require only storage. They also summarize a common criticism of the Just and Carpenter model, claiming it is not surprising that a task so dependant on language predicts comprehension skills because both are tapping the same underlying processes. Span tasks may correlate strongly with different measures of language (Daneman & Merkle, 1996); however the complexity of the span tasks makes interpretation difficult. Do subjects with low scores have difficulty
with storing information, processing it, or integrating the two? Can we measure working memory capacity independently from language?

Daneman and Merikle's (1996) study not only raised the question, but also began to answer it. In addition to traditional span tasks, they examined span tasks that explored other aspect of cognition such as solving arithmetic problems and playing bridge. In one of these studies, Turner and Engle (1989) used a version of the span task that was dependent on math skills. Participants verified whether a series of math problems (e.g. \((2 \times 3) - 2 = 4; (6/3) + 2 = 8\)) were correct and then recalled each of the stated solutions (e.g. 4, 8). Daneman and Merikle (1996) included all similar studies investigating the relationship between math spans and language comprehension measures in their meta-analysis. They found that math measures which include processing and storage elements are good predictors of language comprehension. Caution must be used in the interpretation of these results because numbers are still inherently language based. It remains unclear whether measures of working memory which are independent of language, but still require both storage and processing, are still able to predict comprehension and other language skills.

The 3 models of working memory (Baddeley, 1986; Just & Carpenter, 1992; MacDonald & Christiansen, 2002) come from differing theoretical backgrounds, and it is therefore difficult to directly compare and contrast the differing models. Issues such as the modularity of working memory, balance between storage and processing, usefulness of the central executive, and link to language, invite further research. Each model asks different questions about these different issues. The current study will investigate aspects of these 4 issues within a sample of both typically developing and language impaired
children. The next section outlines current research linking specific language impairment and working memory.

1.4 Specific Language Impairment (SLI)

1.4.1 Definition and nature of SLI

Leonard (1998) defines children with SLI, as showing “a significant limitation in language ability, yet the factors usually accompanying language learning problems – such as hearing impairment, low non-verbal intelligence test scores, and neurological damage – are not evident” (p. 3). For these reasons the study of children with SLI is unique as it allows researchers to investigate the dissociation between language and other areas of knowledge and behavior (Johnston, 1997). However, evidence suggests that children with SLI also show deficits in visual imagery, symbolic play, perception and attention (Johnston, 1997). The above definition is therefore too simplistic as children with SLI do show subtle cognitive difficulties and the dissociation between language and cognition is incomplete.

Current research outlines at least 8 different hypotheses of the nature of SLI (summarized by Gillam, Cowan and Marler, 1998). Some researchers suggest language deficits underlie SLI (e.g. Gopnik & Crago, 1991) while others believe the deficits are not specific to language, and instead extend to other domains (e.g Gillam et al., 1998; Ellis Weismer et al., 1999). Tallal and colleagues (e.g. Tallal et al., 1981; Tallal et al., 1996) were the first to suggest that difficulties underlying SLI may be more pervasive, originating outside the domain of language. Their research has focused on deficits within auditory perception, suggesting that temporal processing deficits might explain the
language patterns of SLI children. Tallal and colleagues opened the door for considering 
deficits beyond the language domain; however their theories continue to remain within 
the auditory system. Further evidence suggests deficits which may extend beyond the 
closely related auditory domain into visual-spatial skills of children with SLI.

1.4.2 Visual-spatial skills of children with SLI

Doehring (1960) first suggested that children with SLI (or developmental aphasia, 
in the terminology of the time) experienced difficulties in visual perceptual ability. He 
found that a group of children with SLI was able to remember the location of fewer visual 
stimuli than control groups of typically developing and deaf children.

Reggin (2002) further investigated the storage capacity for visual-spatial 
information in children with SLI, and her findings were somewhat contradictory to those 
of Doehring. Her task, similar to a traditional visual span task, required that children 
remember the location of monsters within a 4 x 4 grid. The number of monsters 
increased from 2 to 7; a child’s span was calculated as the highest number of monsters 
that could be successfully recalled in at least 80% of trials. Reggin compared a group of 
language impaired children to a group of age peers (matched on nonverbal intelligence) 
and found that the children with SLI were able to store and recall slightly less visual- 
spatial information than their peers, though this difference was not significant. Although 
these results suggest that children with SLI might not have a deficit in storing visual- 
spatial information replication of this finding is needed. In addition, how does this 
finding change when considering the demands of processing in addition to visual-spatial 
storage?
Johnston and Ellis Weismer (1983) first explored the visual-spatial processing abilities of children with SLI using a mental rotation task. Twelve language impaired children and 12 age-matched peers determined whether two rows of shapes were in the same order. Task difficulty was manipulated by rotating the shapes of one line in differing degrees. The researchers interpreted the results, of a linear relationship between degree of rotation and reaction time in both groups, as evidence that all children were using imagistic processes. Results indicated that children with SLI did not differ in the strategies they used to solve the problem but did differ in their response speed. Children with SLI were slower to respond, suggesting impairments in visual processing.

Together, these studies of visual-spatial storage and processing provide initial evidence that the deficits of SLI children might extend beyond the auditory modality, particularly when processing demands are high. Two recent theories of the underlying deficit in children with SLI can account for processing deficits in both auditory and visual modalities: the general processing deficit, and a deficit in working memory.

1.4.3 General processing deficit

The general processing deficit account of SLI posits that the language difficulties of children with SLI might not be linguistically grounded. Instead it is suggested that “a fundamental difficulty in executing mental operations underlies performance in an effective way” (Windsor, 2002). Miller, Kail, Leonard and Tomblin (2001) conducted a large-scale study of processing speed in children with SLI using 41 tasks, both linguistic and non-linguistic in nature. Children with SLI were significantly slower than their peers to respond across the range of tasks. This research provides strong evidence for a generalized slowing of processing among children with SLI, not just in linguistic tasks,
but also in the visual-spatial tasks of mental rotation and visual search. Across all tasks, children with SLI responded at a rate 14% more slowly than their peers.

Windsor (2002) further examined the general processing deficit hypothesis and suggested it was too simplistic. She argued for the importance of considering task domain when investigating generalized processing. She contrasted general and specific processing specific accounts of language impairment and suggested that these accounts might not be mutually exclusive. In a specific processing account, specific mental operations (e.g. linguistic retrieval) support language in different ways, and only some of these mental operations are thought to be deficient in children with SLI (Windsor, 2002). There could be differences between domains, such that within a specific domain, a process could be slowed even more than a system-wide generalized slowing. The working memory account of SLI is not exclusive from a generalized processing account, but provides a particular framework to explore the generality or specificity of processing.

1.4.4 Working memory and SLI

Working memory research is one area that begins to explore the generality or specificity of processing across different domains. Baddeley’s model contains many different possibilities of general and specific deficits, for example, a specific deficit in which a problem lies in the storage of phonological information within the phonological loop slave system, or a generalized difficulty in integrating information from different modalities. Recently, many researchers (e.g. Ellis Weismer and colleagues, Montgomery, Gathercole and colleagues) have begun to explicitly explore the role of working memory deficits in children with SLI (both general and specific in nature).
Research in working memory and SLI initially focused on the most clearly understood components of Baddeley's model (i.e. phonological loop) but has recently branched out to include the more complex aspects (i.e. central executive). The research linking working memory and language impairments will now be reviewed.

1.4.4.1 Phonological loop in SLI

Gathercole and Baddeley (1990b) were the first to investigate the role of the phonological loop in language learning among children with SLI. Using a non-word repetition task, they compared a group of 6 language-impaired children to 2 groups of typically developing peers matched on verbal and non-verbal abilities. The children with SLI were able to repeat fewer non-words containing 3 or more syllables than either control group. These findings were interpreted as evidence that children with SLI have a diminished phonological loop storage capacity, relative to their peers.

Since this study, other researchers have confirmed the finding that children with SLI have a decreased phonological loop capacity as evidenced by performance on the non-word repetition task (e.g. Montgomery, 1995; Dollaghan & Campbell, 1998; Ellis Weismer, Tomblin, Zhang, Buckwalter, Chynoweth, & Jones, 2000). Montgomery (2002) argues that it is not clear whether the deficit in phonological loop capacity is primary or secondary to a subtle phonological processing problem. For example, a difficulty with temporal processing may present as a phonological loop capacity deficit. Although it is clear that children with SLI have a deficit in the phonological loop capacity, this does not preclude deficits in other components of the Baddeley (1986) model, namely the VSSP and the central executive. In fact, as the phonological loop reaches maximum capacity and greater demands are placed on the central executive in
allocating resources, it is reasonable to postulate that deficits may also extend to the central executive and VSSP.

1.4.4.2 Visual-spatial sketchpad in SLI

Only one study (Reggin, 2002) has explicitly explored the VSSP storage capacity in children with language impairments. The fact that visual-spatial activities are a relative strength of children with SLI and that VSSP research of any sort has been minimal, may explain why no other research has been done in the area of VSSP storage capacity and children with SLI. As reviewed earlier, Reggin (2002) found that children with SLI do not have a significantly reduced VSSP capacity relative to their age-matched peers. Given the evidence that children with SLI might have subtle difficulties processing visual information (Johnston & Ellis Weismer, 1983), more research examining the storage and processing of visual-spatial information in SLI is needed to clearly understand this domain and how it may relate to general or specific processing deficits.

1.4.4.3 The central executive in SLI

Very little research has explored the role of the central executive in general and only two projects have examined the role of the central executive with SLI. First Ellis Weismer (1996) conducted a dual processing task in which children listened to two simultaneous sentences, one spoken by a man and one spoken by a woman. They were instructed to first carry out the woman’s instructions and then the man’s instructions. Results from this dual task were compared to single task results, where children heard only one voice. Ellis Weismer found that children with SLI showed relatively more decline between single and dual task performance than their peers. An important
difference between the tasks in Ellis Weismer (1996) and traditional dual tasks is that Ellis Weismer combined two tasks from the same modality, as opposed to one auditory-verbal and one visual-spatial task. Both tasks in Ellis Weismer (1996) relied on the same storage buffer (the phonological loop); thus, results from this study are difficult to interpret. It is impossible to attribute the deficit demonstrated by children with SLI solely to the central executive as the phonological loop function could explain the results.

A second study investigating the central executive was conducted by Reggin (2002). She considered the role of the central executive in the coordination of information from different modalities in both typically developing and language impaired children. Elementary school-aged children participated first in single tasks, one testing the storage capacity of the visual-spatial sketchpad (details as described above) and the other examining the phonological loop (non-word repetition task; Dollaghan & Campbell, 1998). Once each child’s individual span in each single task was determined, the two tasks were combined in a dual task at that child’s span. In this way, the storage demands were equally difficult for each child, and unusual decrements in task performance during the dual task could be attributed to central executive difficulties not storage difficulties. Using this procedure, Reggin (2002) did not find significant differences between groups on the dual task which suggests that children with SLI show intact central executive functioning.

There were two limitations to the Reggin (2002) study that will be addressed in the current study. Firstly, all the tasks measured only storage, and therefore provided little insight into the role of the central executive when managing both storage and processing functions. Secondly, the two tasks were not truly simultaneous, and therefore
not a pure dual task. In the Reggin task, children first encoded the visual stimuli, then completed a non-word repetition task, and finally were asked to recall the location of the visual stimuli. In this way the task was sequential, not simultaneous.

1.4.4.4 Research investigating processing and storage

A few studies have been completed that examined the working memory skills of children with SLI from a perspective of balancing processing and storage demands (e.g. Ellis Weismer et al., 1999; Montgomery, 2000a, 2000b). Ellis Weismer et al. (1999) used the Competing Language Processing Task (CLPT) developed by Gaulin and Campbell (1994) to investigate how children were able to manage the tasks of processing and storage. This task presents groups of 1-6 sentences (e.g. Pumpkins are purple.) and children must verify their truth by responding yes or no. Once all the sentences have been presented, children are then asked to recall the final word of each sentence. Results indicated that the language-impaired children were able to process the sentences as well as age-matched controls (near ceiling level), however they were not able to store and recall as many sentence-final words.

Montgomery (2000a, 2000b) criticized the use of the CLPT as a measure of working memory because processing demands remain stable even when storage demands systematically increase with the number of sentences presented. He modified the CLPT to create a measure in which children were required to recall a list of words (e.g. cow, tree, mouse, seed, cat) in each of three conditions with increasing processing demands. In the no-load condition, children were asked to recall a list of words with no constraints placed on the order of recall. In the single-load condition, children had to re-organize the words based on size of the referent (e.g. seed, mouse, cat, cow, tree). The dual-load
condition required children to perform 2 mental operations, organizing the words for recall by both referent size and semantic category for recall (e.g. seed, tree, mouse, cat, cow). The processing demands increased across conditions, while the storage demands increased with the number of words in a given list.

Using this task, Montgomery (2000a, 2000b) compared the working memory capacities of language impaired children with two control groups: age-matched and language matched children. In both studies, there were no differences in the storage abilities of language impaired children, relative to their peers, when processing demands were kept low (i.e. no-load and single-load conditions). Group differences only emerged when high processing demands were placed on the subjects, such that in the dual-load condition, both the language impaired and language-matched groups performed more poorly than the age matched controls, who showed no condition effect. Montgomery interprets these results as evidence that children with SLI have a reduced verbal working memory capacity relative to their age-peers.

Storage and processing in the visual-spatial modality in children with SLI has attracted even less attention. Ellis Weismer (2002) created a spatial working memory task that required both processing and storage of spatial information. In this task, SLI and age-matched adolescents were shown a long rectangle, divided into 3 squares that each contained a shape. Two shapes were identical, and the subject was asked to find the one that was different (a processing task). Between 2 and 6 rectangles were presented in a trial. After the processing task, participants were presented with a blank grid and asked to recall which square had contained the oddball shape in each rectangle (a storage task). The researchers found no significant differences between groups in the processing task.
(all children approached ceiling levels), however the children with SLI were not able to store and recall as much spatial information as their peers. So, unlike the results of Reggin (2002), who found that children with SLI do not have a deficit in visual-spatial storage, Ellis Weismer (2002) found that children with SLI do have more difficulty storing this information than their peers once a processing component is added.

1.4.4.5 Correlating working memory and language

The research described above has demonstrated group differences on working memory tasks between groups of SLI children and their peers, which implies a connection between working memory and SLI. Recent investigations of children with language impairments have explored the connection more explicitly by investigating how performance on working memory tasks predicts different language skills. For example, Baddeley and colleagues found that phonological loop capacity predicted vocabulary growth (e.g. Baddeley et al., 1998; Gathercole & Baddeley, 1989, 1990a, 1990b). Also, Gaulin and Campbell (1994) correlated vocabulary growth with the Competing Language Processing Test. Further research has focused on higher levels of language processing including morphological learning, sentence comprehension and narrative production (e.g. Ellis Weismer, 1996; Montgomery, 1995, 2000a, 2000b; Pontin, 2002).

Ellis Weismer (1996) was interested in higher levels of language processing and researched the link between working memory and morphological learning in children with language impairments. She created a task where children listened to grammatical morphemes embedded in simple carrier phrases, presented at differing rates (normal, fast, slow). She found that children with SLI comprehended an equal number of morphemes as their peers, but produced fewer of these morphemes than the control group when the
morphemes were presented at a fast rate (stressful processing conditions). Production of morphemes at a fast rate was also found to correlate with working memory task performance. Ellis Weismer (1996) suggests this pattern of results can be explained by a difficulty in managing the demands of phonological processing and storage simultaneously among the SLI children. Montgomery (2002) suggests an alternative interpretation. He proposes that listening to words at a fast rate could affect phonological encoding, or there could be an output processing problem which would explain why children with SLI had difficulty with the faster rate presentation. The initial finding is interesting and presents a continuation of research aimed at understanding the links between working memory and language.

In a second study, Ellis Weismer et al. (1999) examined the relationship between working memory (indexed by the CLPT) and 3 standardized language measures. No correlation between the CLPT and language measures was found; however, Ellis Weismer et al. (1999) argued the standardized tests were not detailed enough to detect the differences.

Later, Montgomery (1995, 2000a, 2000b, 2002) explored the relationship between phonological loop capacity and sentence comprehension. In the first study (Montgomery, 1995), a language-impaired group was matched to a control group based on syntactic knowledge so that any group differences could be attributed to working memory and not inferior syntactic knowledge. The children with SLI showed reduced phonological loop capacity and comprehended fewer long sentences than the control group. These results suggest that a reduced phonological loop capacity compromises sentence comprehension but only when the sentences increase in length. A follow-up study (Montgomery, 2000a)
asked the same question, though in this research working memory was indexed using a
task that required both storage and processing. Again, Montgomery found that children
with SLI comprehended fewer long sentences than the control group. However, this time
there was no correlation between working memory and sentence comprehension.
Montgomery (2000a) suggests this result is not surprising given that the control group
scored near ceiling levels on the sentence-processing task. In addition, Montgomery
argues the sentence-processing task may have overtaxed the general processing resources
of the SLI group. One final study (Montgomery, 2000b) again examined the link
between working memory and sentence comprehension, with an online, rather than
offline, sentence comprehension task. No correlation between working memory and
online sentence comprehension was found, suggesting that working memory as measured
by Montgomery’s storage and processing task plays no role in immediate language
processing. The investigation of online and offline processing and how working memory
might contribute to our understanding represents an important area of future research.

Pontin (2002) examined the role of working memory in narrative production of 5-
year-old children both with and without language impairments. She correlated results
from Montgomery’s (2000a) working memory tasks (i.e. recall of word lists with no
constraints and with reordering by size of referent) with various measures of narrative
coherence, and found preliminary support for a correlation. There was a significant
negative correlation between the working memory task and proportion of nongoals (r =.49). Nongoals are units of information that are not relevant to any goal (e.g. descriptive
comments and labelling). Results from her study were difficult to interpret due to the
young age of the subjects that resulted in floor effects. The working memory task was
very difficult for all subjects, particularly the language-impaired group (none succeeded in achieving a span of 3 or greater). Due to these methodological concerns, caution must be taken in interpreting the results, however the possible relationship between working memory and narrative production invites further investigation.

In summary, research investigating the correlation between working memory and language has found firm evidence that working memory skills predict vocabulary development though the link between working memory and other levels and domains of language remains inconclusive.

1.5 The Current Project

Research examining the role of the central executive remains limited, particularly when examining the role of the central executive in clinical populations, such as in children with language impairments. In addition, there is still much disagreement about the usefulness of a conceptual ‘central executive’, and if it does indeed exist, about how to portray it (Baddeley, 1996; Towse & Houston-Price, 2001b). The current study will examine one potential central executive function, combining information in a dual task paradigm, within a population of both typically developing and language impaired children. One set of tasks will require children to balance processing and storage demands. Another set of tasks will require children to balance information from auditory and visual modalities. In addition, the correlations between working memory and narrative production will be considered. The results will inform the theoretical models of working memory and specific language impairment.
1.5.1 **Balancing processing and storage within a single modality**

Research that requires children to balance processing and storage demands has been a relatively well-investigated area within the working memory and SLI research. Multiple studies (e.g. Montgomery, 2000a, 2000b; Ellis Weismer et al., 1999) have suggested that children with SLI have more difficulty coordinating processing and storage resources than their peers, at least in the auditory-verbal modality. What remains unclear, both in the wider literature, and in the SLI literature, is whether this same model can be implemented within a visual-spatial modality. The current study will investigate the abilities of children to coordinate both storage and processing resources in the visual-spatial modality in addition to replicating previous work in the auditory-verbal modality. Montgomery’s (2000a, 2000b) tasks will be the basis for this set of tasks. Are children with SLI able to coordinate storage and processing demands in both modalities as effectively as their age-matched peers?

1.5.2 **Coordinating auditory-verbal and visual-spatial information**

Ellis Weismer (1996) and Reggin (2002) have made important beginnings in the study of the role the central executive may play in coordinating dual tasks in language impaired children; however, there is much still to be learned. Another goal of the current study will be to provide some early insight into the integration and coordination abilities of children with SLI. Emerson et al. (1999) found these abilities to be closely related in studies with normal adults. Do these findings extend to children with SLI? Are these children able to coordinate and integrate information across modalities as well as their peers?
1.5.3 Linking working memory and narrative production

The final goal of the current study will be to explore the possible link between working memory and narrative production. Pontin (2002) provided preliminary evidence for the relationship between these two, but can these results be replicated with a different methodology and older children?

1.6 Research Questions

1. Are children with SLI able to store equal amounts of verbal information as their age-matched peers?

Montgomery (2000a, 2000b) has shown that as long as the task is primarily a storage task, children with SLI are able to remember word lists equal in length to those of their peers. Based on this finding, we would expect no group differences between the language impaired and age matched controls on an auditory-verbal storage task.

2. What effect do additional processing demands have on the abilities of children with SLI and typically developing children to store information in an auditory-verbal modality?

A Just and Carpenter (1992) model of working memory, that corresponds roughly to the central executive, suggests that there is a limited capacity of resources available for processing and storage. Montgomery (2000a, 2000b) found that once processing demands increase, children with SLI are no longer able to store as much information as their peers. This study will attempt to replicate this initial finding.
3. Are children with SLI able to store equal amounts of visual-spatial information as their age-matched peers?

Reggin (2002) provided preliminary evidence that children with SLI show no deficits in visual-spatial storage tasks.

4. What effect do additional processing demands have on the abilities of children with SLI and typically developing children to store information in a visual-spatial modality?

Johnston & Ellis Weismer (1983) provide preliminary evidence that children with SLI do have difficulty in processing visual information. Will this result be replicated?

5. Do group differences in the effect of additional processing demands depend on modality?

If children with SLI have a general processing deficit as suggested by Gillam et al. (1998) we would expect processing demands to influence both modalities; however, if processing limitations are restricted to verbal material, we would expect to see differences between modalities, relative to the control group.

6. Are children with SLI able to coordinate information in a dual task paradigm as effectively as their AM peers?

Reggin (2002) found no deficit in SLI children's ability to coordinate information, provided the single tasks were presented at an equivalent level of difficulty to all participants. There were, however, methodological difficulties in task design in this study. Can these findings be replicated in the current study?

7. Are children with SLI able to integrate information in a dual task paradigm as effectively as their AM peers?
Emerson et al. (1999) found a strong correlation between coordinating and integrating abilities in adults. Does this same finding apply to children with both typically developing and language impaired children?

8. Is there a correlation between working memory scores and narrative production as indexed by the Test of Narrative Language (Gillam, in press).

Pontin (2002) found preliminary evidence for a correlation between working memory scores and narrative coherence, however there were methodological concerns. Can such a finding be replicated?
2 Method

This chapter provides details of the participants, tasks, and design used in this experiment. First, selection criteria for both the experimental and control groups are outlined. Details of the construction of the 6 experimental working memory tasks follow, along with information about the procedure for completing the inclusionary measures, working memory tests, and narrative tasks. Finally, the experimental method is related back to the research questions.

2.1 Participants

2.1.1 Criteria applying to all participants

All children who participated in this study were attending school in either the Coquitlam or Salmon Arm school districts. A total of 24 children were included, ranging in age from 89 months (7 years, 5 months) to 128 months (10 years, 10 months) (M = 108.29 months, SD = 11.59). Based on language ability, children were divided into two groups: those with language impairments (LI) and those with normal language skills (NL), matched in age. Children suitable for inclusion in the LI group were identified by their school Speech Language Pathologists. Teachers of the selected LI children then identified classmates to be included in the NL group. All LI children were successfully matched to an NL child of the same gender who was no more than 6 months older or younger than the LI subject. Participants in the LI group had an average age of 107.83 months (Range 89 to 125 months, SD = 12.11). The age-matched NL control group had an average age of 108.75 months (Range 90 to 128, SD = 11.55). There were no
significant differences in age between the two groups, \( t(22) = -0.19, p = .85 \). Each group included 7 males and 5 females. The results from two children were not included because they failed to meet inclusionary criteria.

All participants were native speakers of English. In order to be included in this experiment, all children were required to obtain nonverbal IQ scores of 80 or greater, as indicated by scores on the Test of Nonverbal Intelligence (TONI) (Brown, Sherbenou, & Johnsen, 1997); LI (\( M = 97.08, \text{SD} = 10.36 \)), NL (\( M = 103.75, \text{SD} = 11.86 \)). There was no significant group difference on TONI scores, \( t(22) = -1.46, p = .16 \). Finally, all children passed a hearing screening of sound levels at 20dB in the range of frequencies important for speech recognition (500Hz to 4000Hz) (American Speech and Language Association, 1997).

Dollaghan et al. (1999) found a relationship between level of maternal education and speech and language skills in 3-year-olds. Data on maternal education was thus also collected and used as a proxy for socio-economic status. Maternal education was measured in number of years (e.g. high school completion = 12, university degree = 16). Data was unavailable for one LI child and her NL control. No group difference in levels of maternal educations, LI (\( M = 12.00, \text{SD} = 1.90 \)), NL (\( M = 12.64, \text{SD} = 1.36 \)), \( t(20) = .90, p = .31 \), was found in the remaining 22 children.

### 2.1.2 Language criteria: CELF-3

Scores on the Clinical Evaluation of Language Fundamentals-Third Edition (CELF-3) (Semel, Wiig, & Secord, 1995) were used to discriminate between the LI and NL groups. All children completed at least two of the three expressive subtests of the CELF-3. The *Formulated Sentences* and *Recalling Sentences* subtests were administered
to all children. Most children also completed the third expressive subtest suitable for their age, either *Word Structure* or *Sentence Assembly*. Children included in the LI group scored at least 1 SD below the mean on two of the three subtests (a standard score of 7 or less on both subtests). To be included in the NL group, children were required to score 9 or above on at least two of the three expressive subtests of the CELF-3. Table 1 outlines the language and cognitive tests scores for the two groups.

Table 1. Mean (SD) scores for language and cognitive testing for the LI and NL group

<table>
<thead>
<tr>
<th>Age in months</th>
<th>CELF-3 Formulated Sentences M, (SD)</th>
<th>CELF-3 Recalling Sentences M, (SD)</th>
<th>TONI M, (SD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Language Impaired</td>
<td>107.83 (12.11)</td>
<td>4.42 (1.44)</td>
<td>4.25 (1.22)</td>
</tr>
<tr>
<td>Normal Language</td>
<td>108.75 (11.55)</td>
<td>10.25 (1.60)</td>
<td>11.00 (2.45)</td>
</tr>
</tbody>
</table>

As expected, t-tests indicated a significant difference in expressive language scores between the two groups on the two subtests of the CELF-3 that were completed by all children (Formulated Sentences subtest t(22) = -9.37, p <.001, Recalling Sentences subtest t(22) = -8.55, p <.001).

2.1.3 Previous participation

Seven of the language-impaired children had participated in a related study 9 months previous to this experiment (Reggin, 2002). For these children, cognitive and language testing (CELF-3) results from the previous research were used to avoid spurious high scores resulting from frequent testing. In the previous research, these children received only the Formulated Sentences and Recalling Sentences subtests of the CELF-3. Based on these scores, all children met inclusionary criteria, of standard scores of 7 or less on two subtests, so the final CELF-3 subtest was not administered. These 7 children
continue to be followed by the local Speech Language Pathologist, who clinically judges these children to remain in the category of Specific Language Impairment. Current language data were also collected in the form of the Test of Narrative Language (Gillam, in press) for all children, including these 7.

2.2 Experimental Tasks

All children completed a total of 6 experimental working memory tasks and one narrative test across two sessions with the experimenter. Two of the working memory tasks tapped auditory-verbal working memory and two focused on visual-spatial working memory. The final two tasks were dual tasks that required memory of both auditory-verbal and visual-spatial information, in either an integrated or coordinated format. All conditions were presented using E-Prime software (Schneider, Eschman, & Zuccolotto, 2002a, 2002b) on a Hewlett Packard Pavilion N5270 Notebook. The screen on this computer measured 9” x 12” and was covered with a glass screen protector. All auditory information was presented using headphones at a volume level each child deemed comfortable.

2.2.1 Auditory-verbal working memory tasks

2.2.1.1 Background

These tasks were based on the ideas of Montgomery (2000a) who first designed a working memory task suitable for children that was consistent with the Just and Carpenter (1992) model of working memory. Montgomery (2000a) argued that such a task must involve systematic increases in both storage and processing demands. Although the final version of the tasks used in this experiment differ greatly from
Montgomery's original, the basic idea of increases in both storage and processing demands continues to remain central.

2.2.1.2 Stimuli

Twenty-six words were used in the auditory-verbal working memory tasks. Referent objects were selected that would have robust cognitive and linguistic representations in both typically developing and language impaired children. Half of the words chosen represented objects that would fit inside a box (measuring \(8\frac{1}{2}'' \times 3\frac{3}{4}'' \times 4\frac{1}{2}''\)) available to the child during the experiment (e.g. ant, fork, egg). The other half referred to objects too big to fit inside the box (e.g. pig, bed, cake). For each word representing an object that fit inside the box there was another word, from the same semantic domain representing an object that was too big to fit inside the box. Semantic category was thus not a cue to size. For example, 'egg' is a food that would fit inside the box; 'cake' is also a food but would not fit in the box.

Many lexical properties have been found to affect the ease with which we are able to process and recall words. For example, Morrison, Ellis and Quinlan (1992), among others, have found that the age at which we learn a word influences ease of recall even as adults, such that words that are acquired very early in life are retrieved from lexical memory more easily than words acquired later. For this reason, all stimuli words chosen for the current study have an age of acquisition of 30 months or less, as measured by the MacArthur Communicative Development Inventory (Dale & Fenson, 1996)\(^1\).

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\(^1\) The MacArthur Communicative Development Inventory (Dale & Fenson, 1996) was chosen to specify the Age of Acquisition (AoA) because data is available for a large corpus of words and it is representative of standard American English acquisition, which more closely parallels the Canadian English of subjects in this study than British English. AoA data from this source was unavailable for 2 of the 26 stimulus words. The AoA of 'leaf' was therefore taken from Morrison, Chappell, & Ellis (1997). There was no AoA available for 'pie' however the experimenters, who have experience working with young children, both agreed that this was a word generally acquired by age 3.
Other lexical factors known to influence recall include imageability, name agreement, frequency, familiarity and neighborhood density (Morrison, Chappell, & Ellis, 1997). While there is diversity in the findings as to exactly which of these factors influence memory in which sorts of tasks, all have been shown to affect lexical access in some studies. The easiest words to recall are those that are highly imageable, can be pictured in a manner that leads to a high percentage of name agreement, have a low neighborhood density, occur frequently, and are highly familiar. Each of these parameters is defined below, with illustrative evidence to justify their consideration.

**Frequency**: How frequently a word occurs in a language, measured as either spoken or written frequency. Barry, Morrisson and Ellis (1997) found both spoken and written frequency to be major determiners of picture naming speed among adults, such that low frequency words take longer to name than high frequency words.

**Neighborhood Density**: Neighbors are “words that differ from one another by a single phoneme addition, deletion, or substitution in any word position” (Garlock, Walley & Metsala, 2001). For example, the neighborhood of the word ‘bat’ would include such items as ‘mat’, ‘bit’, and ‘ban’. Neighborhood density is the total number of possible neighbors for a given word. Garlock et al. (2001) found that both children and adults were slower to identify words from a dense neighborhood than a sparse neighborhood in a gating task.

**Imageability**: Rating of how easily a word “conjures up a mental image” (Gilhooly & Logie, 1980). Bird, Howard and Franklin (2003) investigated the effect of imageability in predicting naming performance of nouns and verbs in
people with aphasia, and found that in both lexical categories, naming was more successful with words that were highly imageable.

**Name Agreement:** Percentage of respondents agreeing to a single label for a picture. This measure assesses the extent to which a picture is a good example of the item it is meant to represent. For a given set of pictures, a word with a high percentage of name agreement is easier to access and process (Snodgrass & Vanderwart, 1980). Johnson & Clark (1988) found that low levels of name agreement were associated with increased naming difficulties among college students.

**Familiarity:** Familiarity, as defined in the subject instructions in Barry et al. (1997), is “how usual or unusual the thing is in your realm of experience.” Cycowicz, Friedman and Rothstein (1997) found a significant correlation between rated familiarity and latency of picture naming among both children and adults.

It is difficult, if not impossible, to ensure that each stimulus word scores highly on all these properties. Appendix A outlines all the stimulus words and their lexical properties. For the purposes of this experiment, all words were chosen to score as highly as possible across these properties.

All words were recorded by a trained adult female speaker using a head mounted microphone. Words were spoken directly into the HP N5270 computer using Cool Edit 2000 software (1999-2000) at a sampling rate 44,400Hz. Each word was recorded 3 times in the context of the carrier phrase “Say the word...”. Using the Cool Edit program, each token was edited out of the carrier phrase and normalized to 50% of maximum amplitude so that all words had approximately the same intensity. The
experimenter and speaker then took the mean Root Mean Square power (a measure of average intensity) of all tokens for all words, and chose the token for each word that was closest to the mean. Using this method, all words fell within a 6dB range in average RMS power ($M = -25.75$, $SD = 1.38$, where $0 = $ full amplitude square wave).

2.2.1.3 Pretest: Children's understanding of words, categorization skills

Prior to presentation of the experimental auditory-verbal memory tasks, all children were tested to ensure they were familiar with the words used in the task, and that they were able to categorize them according to whether or not they fit in the box.

Understanding of the experimental words was tested using a receptive measure. Thirteen black and white line drawings (on $3\frac{1}{2}$" x $3\frac{1}{2}$" cards) representing half of the stimuli words were laid out on a table (20 pictures from the Snodgrass Vanderwart set, developed by Rossion and Portois (2001)$^2$ & 6 pictures from Microsoft Clipart (http://www.microsoft.com/clipart)). Appendix A provides samples of pictures from both sources. The object names were presented auditorally one by one over the headphones. Children were required to repeat the words and select the matching picture from the cards on the table. Once the first 13 pictures were identified, the same task was repeated with the other 13 pictures and words. During this task, children were encouraged to adjust the volume of word presentation on the headphones to a comfortable level.

Most children found this task easy with no difficulties in identifying the pictures. Two children in the LI group first chose the picture of the 'cake' to match 'pie'. However, when they later heard the word 'cake', both realized their mistake and were able to self-correct. The same confusion occurred between 'egg' and 'soap' for one child.

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$^2$ Images provided courtesy of Michael J. Tarr (Brown University, Providence, RI). Downloaded from http://www.cog.brown.edu/~tarr/stimuli.html
in the NL group. Again, the child was able to self-correct. Other than these minor self-corrected errors, all children correctly matched all words to pictures.

In order to ensure the participants were able to categorize the words according to whether or not they would fit in the box, they were given a simple categorization task. The experimenter showed the child the box and the ‘mouse’ picture and asked whether in real life the mouse would fit into the box. When the child responded ‘yes’, the experimenter modelled putting the ‘mouse’ picture into the box. The same question was repeated using the ‘cow’ card, and when the child responded ‘no’, the experimenter modelled putting this card beside the box. Children were then asked to put all the cards in the right place with no further assistance. Following the categorization task, any errors were corrected with discussion. If a child did make a mistake, he or she was coached to correct the mistake. For example, if the ‘sock’ card was placed outside the box, the child was told, “Let’s pretend it’s a little sock, all wrapped up in a ball. Then it would fit inside the box”. The card was then moved to its correct location. There were only 5 children who made as many as 3 initial errors on the 26 items: 4 in the LI group and 1 in the NL group. Three more children in the LI group made 2 errors. All children readily agreed to the correction of their errors. Of the 8 children who made categorization errors on the pre-test, only 1 made an overt categorization error during the working memory tasks, and it was a word she had successfully categorized.

2.2.1.4 Task 1 Auditory-verbal: Storage

In this task the children listened to a series of words (from 3 to 7 words), and were then asked to repeat them. Words were separated by 1000 ms. intervals and the children were required to repeat the entire series at the end of the presentation. At the beginning
of each trial the computer screen was black. The participants were instructed to press the space bar to begin the task. A bell chime rang as an auditory cue, and then the series of words was presented. At the end of the series, a teal box appeared (500 ms. after the last word) to cue the child to repeat as many of the stimulus words that she could recall. Prior to beginning the task, two demonstration trials were completed by the experimenter to model the task, and the children were asked if they had any questions.

Initially the children completed 5 trials, each containing a list of 3 words. Children controlled when to move to the next trial by pressing the space bar. If the child failed to respond correctly on the first trial, he was coached to the correct answer. No constraints were placed on the order of recall of the stimulus words. For example, though a trial may be presented 'pie, watch, leg', a response of 'watch, pie, leg', would be considered correct. For each trial, the experimenter recorded complete responses on paper, and entered whether a child was correct or incorrect into the computer.

If at least 3 of the first 5 trials were completed successfully, the experimenter informed the child that there would be more words in the next trials. Four trials, with a list of 4 words each, followed. If children were again successful on 3 of the 4 trials, the number of words increased to 5 for the following 4 trials. This pattern continued until a child was successful on less than 3 trials at any given level or until the child completed the trials at the highest level, 7 words. If at any time, a child was successful on only two of the trials at a given level, the first trial of the next level was presented. The task ended if the child was unsuccessful, but continued if she was successful. Children were thus able to perform at their best levels and no inaccurate ceiling results occurred.
A child’s span was calculated as the highest level at which he performed successfully on at least 3 trials. Children who were unable to complete the easiest level (3 words) were assigned a span of 2, and children who were still accurate on the hardest level (7 words) received a span of 7, though they might have been successful at a higher level.

All children heard the same word list on a given trial. For example, the third item at level 3 was always “fridge, egg, mouse”. The construction of these trials, and the words they contained, was done in a random manner with the following constraints. In all trials with an even number of words, half of the stimulus words referred to items that would fit in the box and half did not. In trials with an odd number of words, the balance of these items across trials was kept as close to 50%/50% as possible. No two items beginning with the same phoneme or minimal pairs were presented in the same trial. No word was repeated in adjacent trials. If possible, each trial contained words from different semantic categories. As the number of words presented in a single trial increased past 5 words, it was necessary to allow 2 words from the same semantic category to be included within one trial.

2.2.1.5 Task 2 Auditory-verbal: Processing

This task was designed to investigate the influence that additional processing demands would have on the ability to recall words. A set of trials was designed and presented based on the procedure described in Task 1, the storage task. In this task, the cue to recall the stimulus words was altered. Rather than a single teal box in the middle of the screen as a cue to recall the words, two boxes were pictured on the screen. A teal box on the left of the screen had the word ‘box’ printed underneath and an equal-sized
maroon box was pictured on the right. Children were reminded that “some objects fit in the (real) box, and some were too big”. The children were instructed to categorize the items according to whether they would fit into the box or not. First they were to recall the smaller objects and point to the teal box, and then they were to recall the larger objects while pointing to the maroon box. If children alternated between boxes, the stimuli were not repeated, but they were asked to try again, with all the smaller objects first. If they were unable to correctly categorize in this way, the response was considered wrong.

As in Task 1, this was demonstrated in two trials by the experimenter. Following each demonstration trial, the rationale was repeated, by pointing and saying “X and X fit in the box, but X is too big”. Children were asked if they had any questions before beginning the test trials. Again, if a child failed to get the first trial right, the experimenter coached her with the correct answer. A child’s span was determined as the highest level at which she was able to correctly repeat all words, categorizing them to first say the small items and then the big items in at least 3 trials.

All other details of presentation remained consistent with Task 1. Task 2 was always completed following Task 1 because pilot testing indicated asymmetries between the two conditions. Strategies provided during Task 2 would likely interfere with Task 1 performance. In addition, given the relatively small number of trials, one could expect practice effects to significantly impact performance on Task 2; it is important to ensure practice effects remain consistent across all participants.
2.2.2 Visual-spatial working memory tasks

2.2.2.1 Background

The visual-spatial working memory tasks follow from the work of Reggin (2002), and attempt to incorporate additional processing demands consistent with Just & Carpenter's (1992) model of working memory. As in the auditory-verbal tasks, one task is designed to tap primarily storage resources, and one incorporates additional processing demands.

2.2.2.2 Stimuli

The stimuli in the visual-spatial working memory tasks were simple 3-dimensional green shapes. They were organized on a 4 X 4 square grid (white squares of 4.25cm$^2$ on a black background with .5cm separating the squares). Ten objects were chosen from the 3D part-based object database$^3$ that were judged by the experimenter to be the most difficult to name. Objects resembled simple distorted geometric figures and were not easily nameable. Appendix B shows sample objects. On any given trial, approximately half of the objects were of one randomly chosen type and half were of another randomly chosen type. Across trials, the number of squares filled with an object increased from 3 out of 16 squares to 7 out of 16 squares.

The distribution of shapes within the grid was constrained by two rules; 1) no two adjacent squares were filled, 2) no two squares in the same row or column were filled (in the first two levels using fewer than 4 shapes per trials). Thus all grids within a single level were of relatively equal difficulty. For example, a grid with objects lined up in the four squares of the top row would be easier to remember than one where the four objects

$^3$ Images provided courtesy of Michael J. Tarr (Brown University, Providence, RI). Dowloaded from http://www.cog.brown.edu/~tarr/stimuli.html
are scattered in different rows and columns. These constraints had been intended to limit children’s ability to use verbal coding strategies, following preliminary tests indicating that children attempted to label the overall patterns formed by the filled squares. At lower span levels, these constraints were generally successful, however at higher span levels (where more stimuli were distributed throughout the grid), comments from some children indicated they were able to deduce these constraints and use them as a strategy to assist in memory. One child commented, “You always skip one.” On a given trial, the configuration of the objects was the same for all children.

2.2.2.3 Task 3 Visual-spatial: Storage

The visual-spatial storage task was designed to tap storage capacities, while limiting the amount of visual-spatial processing required to complete the task. The 4 X 4 white on black grid was used. Children were asked to recall the position of squares which contained shapes after having seen the stimulus presented for 3500 ms. 500 ms. of a black screen followed before another grid appeared with question marks in all the squares. The child recalled where the objects were located by pointing to the appropriate square within the ‘question-mark’ grid.

As in the auditory-verbal tasks, instructions presented to the children were minimal. Children were told to remember the shapes’ location, and the experimenter demonstrated this with the first two trials. Children controlled the rate of presentation by pressing the space bar to begin each trial. While the objects were visible and children were encoding information, they were allowed to use any strategy, including pointing to and touching the filled squares. However, when the objects disappeared, children were required to remove their hands from the screen briefly before responding.
Children were required to successfully complete a minimum of at least 2 out of 4 trials at any given level, before they moved to a higher level and the number of stimuli in the grid increased. Span was identified as the highest number of filled squares the child could successfully remember for at least 3 trials.

Two different shapes were presented per trial to maintain consistency with the upcoming visual-spatial processing task though children’s attention was not drawn to this difference. Some children appeared to group the shapes by first pointing to all of one type and then all of another, but not all children did this and this practice decreased as the number of objects increased. No child explicitly commented about the two different shapes.

2.2.2.4 Task 4 Visual-spatial: Processing

As in the auditory-verbal tasks, a second visual-spatial task was designed which added an element of processing to the demands presented by the visual-spatial storage task. The additional processing required in this second task built on the storage task and was thus consistently presented after the first task.

For this second task, children’s attention was drawn to the two different shapes presented in each trial. They were instructed to remember both the location and the type of shape presented on the screen. Presentation of stimuli remained consistent with the storage task, with the exception of the final ‘question-mark’ grid. On this final grid, an additional two boxes were located at the tope of the screen, which each contained one of the two shapes presented in that trial. Children were required to point to the locations of all of one shape before pointing to the locations of all of the second shape. The experimenter demonstrated the task by pointing to all the squares that contained one
shape then to the square on top with that same shape. The next step in the response was to point to all the squares that contained the second shape, then the matching shape on top. In the two demonstration trials, the experimenter pointed once to the shapes matching the left hand square first, and in the second trial, began with the shapes matching the right hand square. This practice demonstrated to children that it did not matter which shapes they pointed to first as long as they were able to match them. Again, children were given feedback and corrected on the first trial.

At first, this task proved to be difficult for some children to understand. If the child provided an answer that showed evidence of categorization, but not in the format required, children were prompted to try again. One example of this type of response was when children pointed to the shape on top, before pointing to the squares in the grid. The other example was when children correctly matched location with shape, but failed to group locations together (i.e. pointing to one square followed by the matching shape, rather than pointing to all the squares of a particular shape before identifying the shape). In both cases, the input was not repeated. If a participant could still not correctly meet task format, the response was scored as incorrect. Despite the apparent complexity of this task, following the first few trials, children caught on quickly and seemed to have little difficulty understanding what was required of them.

Requirements to move to more difficult trials, and calculation of span was consistent with all previous conditions.
2.2.3 Dual working memory tasks

2.2.3.1 Background

A second method of exploring the role of the central executive in children with SLI was to design two conditions that required children to coordinate or integrate information coming in from both visual and auditory modalities. In the coordinating task children were required to remember both visual-spatial and auditory-verbal information, but were not required to integrate the two in any way. The integrating task required children to combine the two sources of information such that a particular word matched the location of a shape.

2.2.3.2 Stimuli

Auditory stimuli were the same as those used in tasks 1 and 2. Visual stimuli matched those used in tasks 3 and 4, except that in any given trial there was only one type of shape, unlike the two different types used in earlier visual-spatial tasks.

2.2.3.3 Task 5: Coordinating task

The coordinating working memory task was essentially a combination of the auditory-verbal and visual-spatial storage tasks. Children heard a list of words, as in Task 1, while simultaneously viewing a grid that contained objects. The number of words and number of squares filled with objects was always equal. For example, children began by hearing a list of 3 words and viewing a grid with 3 full squares. Following the presentation of the final auditory word, the visual grid was replaced by a black screen for a 500ms break and then children were cued with a teal square to begin the verbal response. The teal square appeared for a duration of 3000ms during which time children repeated the list of words they had heard. Then, a grid full of question
marks replaced the teal square, prompting children to recall the location of objects. The duration of 3000 ms for a verbal response was chosen following pilot testing as an appropriate amount of time such that children were able to produce all the words they needed, but not so long as to distract them from the task of remembering the visual-spatial information. As in previous conditions, instructions were kept to a minimum and children were told that now they were going to “play the looking and listening games together”. Requirements for determining span and moving to higher levels were consistent with all previous conditions.

2.2.3.4 Task 6: Integrating task

The final task working memory task again presented both auditory-verbal and visual-spatial information; however, this time, children were required to integrate the information from the two modalities. A ‘ding’ sound and blank grid oriented children to the beginning of the task. A list of words was presented over the headphones. Simultaneous to the presentation of each new word in the list, an object appeared in a single square and remained present for the duration of the trial. This method of visual presentation differed from all previous tasks, as squares were filled one at a time, rather than all appearing at the start of the trial. The rationale for this temporal change was to connect each filled square to a particular word, thus requiring integration. Following the completion of the word list, a black screen appeared for 500ms followed by the response grid. The experimenter modelled pointing to a square and saying the word that had been spoken when the square had been filled. Again, despite the complexity of the task, most children appeared to understand the task demands quickly and easily. In all other ways, the presentation of trials followed the previous tasks.
2.2.4 Scoring

All scoring was completed online during the tasks. In order to ensure reliability of online scoring, a total of 393 trials of different tasks were recorded and then scored by a second independent examiner. The offline and online scorers agreed on 388, or 99% of these 393 trials. Agreement ranged from 93% to 100% across the different tasks; the lowest agreement levels occurred on the visual-spatial processing task.

2.2.5 Narrative task: Test of Narrative Language

All children also completed the standardized Test of Narrative Language (Gillam, in press). This test measures both expressive and receptive narrative abilities of children, and takes approximately 20 minutes to administer. There are 3 sections, each consisting of a comprehension and oral narration part. In the first section, the child must listen to a story about a visit to McDonald’s and then answer comprehension questions before retelling the story. In the second section the child listens to a sample story about a school project told from a sequence of pictures and is again asked to answer basic comprehension questions. Following this the child is given another set of pictures, depicting a child who is late for school, and is asked to create his own story. The third and final task repeats the procedure from section 2; however, the stories are based on a single picture rather than a series of pictures. This task was tape-recorded for scoring purposes.

Scoring followed the standardized criteria of the TNL, and was completed by an experimenter who was not present at the time of testing and did not know the child. The TNL gives each child a raw and standardized score in the areas of Narrative Comprehension and Oral Narration. Another independent coder scored 4 TNL, 2 from
children in the LI group and 2 from children in the NL group to ensure reliability of scoring. Mean individual item agreement for these 4 TNL was 87%.

2.3 General Procedure

The 6 working memory and one narrative experimental tasks, together with the inclusionary measures took place over 3 approximately 40-minute sessions. During the first session, children completed a hearing screening, the TONI, and the CELF-3, in order to ensure they met the criteria for belonging to either the LI or AM groups. The second session consisted of the first 4 experimental tasks. The auditory-verbal and visual-spatial tasks were counterbalanced such that half of the subjects began with the auditory-verbal tasks and the other half began with the visual-spatial tasks. In both cases, the storage task was completed prior to the processing task because it was believed that the instructions for the processing task would likely interfere with performance on simple storage tasks, and that it was important to maintain any practice effects consistently across all subjects. The pre-test of children's vocabulary and categorization skills was completed immediately before the auditory-verbal storage task. During the final session, children completed the Test of Narrative Language and the final two experimental tasks.

The order of presentation of the narrative and experimental tasks was counterbalanced across subjects. Pilot testing indicated asymmetries between the integrating and coordinating tasks. The integrating task provided children with a strategy, matching each word to a square that could influence the method children used to complete the dual task. For this reason, no counterbalancing was used, and all children
participated in the coordinating task before the integrating task. Children appeared focused and able to maintain attention well across the demands of all 3 sessions.

All sessions were conducted by one of two experimenters, both graduate students in Speech Language Pathology. Each experimenter scored the TNL of the children to whom they did not personally administer the test. All children also participated in a separate experiment exploring strategy use in visual-spatial working memory tasks, which took place in one final session, following the sessions just described.

2.4 Analysis Strategy

The first four research questions investigate the storage and processing abilities of children with LI in relation to their NL peers. Performance on the two auditory-verbal tasks (storage, storage + processing) and two visual-spatial tasks (storage, storage + processing) will answer these questions. A comparison of the effect of processing in each modality among children with LI and NL will be done by comparing the decrement between the storage and storage + processing tasks in the auditory-verbal and visual-spatial modalities.

Research questions #6 and #7 ask whether children with SLI are able to coordinate and integrate information from different modalities as effectively as their peers. These questions will be answered using the results from Tasks 5 (Coordinating) and 6 (Integrating). Performance between groups on these two tasks will be compared.

The final research question addresses the possible connection between working memory skill and narrative production. Results from the standardized Test of Narrative
Language will be correlated with the auditory-working memory Tasks in order to further explore this possible link.
3 Results

3.1 Analysis Strategy

The purpose of this study was to investigate storage and processing abilities across modalities in children with language impairments. In addition, possible associations between working memory and narrative skills were explored. In order to answer the research questions, performance on the single modality working memory tasks for the LI and NL groups will be compared using Analysis of Variance (ANOVA) procedures first within each modality, and then across modalities. Measurement challenges when comparing results from different modalities justify the initial use of single modality analysis since we cannot assume the psychological equivalence of span levels in the auditory-verbal modality and the visual-spatial modality. However, the group differences across modalities are also significant to the current experiment; therefore, the 3-way interaction between group, modality and level of processing will be examined using z scores to compare the relative performance levels of children in the two groups. The results of the dual tasks will then be presented using nonparametric methods, a change in analysis procedures that is necessitated by large floor effects in these two tasks. Finally, the correlations between the working memory tasks and the Test of Narrative Language (TNL) will be examined.

3.2 Auditory-Verbal Working Memory Tasks

The first set of analyses was designed to assess the differences in language-impaired children’s ability to store and process auditory-verbal information relative to their age peers. Means and standard deviations for the working memory spans of each
group on the two auditory verbal tasks, i.e. storage and storage + processing appear in Table 2.

Table 2. Mean (SD) span in auditory-verbal working memory tasks for children with language impairments (LI) and normal language (NL)

<table>
<thead>
<tr>
<th>Group</th>
<th>Storage M, (SD)</th>
<th>Storage + Processing M, (SD)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Span</td>
<td>Span</td>
</tr>
<tr>
<td>Language Impaired</td>
<td>2.92 (.67)</td>
<td>2.50 (.67)</td>
</tr>
<tr>
<td>Normal Language</td>
<td>3.58 (.79)</td>
<td>3.83 (.72)</td>
</tr>
<tr>
<td>Both Groups</td>
<td>3.25 (.79)</td>
<td>3.17 (.96)</td>
</tr>
</tbody>
</table>

These results indicate that the LI children had lower spans and completed fewer trials accurately than their peers, particularly on the task that required processing in addition to storage. Statistical tests were computed to test the reliability of these findings. Preliminary tests for homogeneity of variance (Levene, p>.05) indicated that this distribution assumption had been met. Therefore, differences between the NL and LI groups on the auditory-verbal working memory spans were analyzed using a two-way mixed model ANOVA with one between subjects factor (Group) and one within subjects factor (Level of Processing).

The ANOVA yielded a main effect of group, F = 14.73; df = 1, 22; p < .02. In comparison with their NL peers, LI children achieved lower auditory-verbal spans. Effect size, measured by partial eta-squared, was .40. There was no significant main effect of level of processing, F = 0.40; df = 1, 22; p > .02. There was, however, a significant interaction between group and level of processing, F = 6.40; df = 1, 22; p < .02. Post hoc tests of the interaction (Fisher LSD, a=.05) indicated that children in the
SLI group showed a significant decrease in span with increased processing demands, but children in the NL did not. Effect size, measured by partial eta-squared, was .23.

The auditory-verbal processing task was difficult for all children, but particularly difficult for the LI children. 7 children in the LI group were unable to succeed on 3 of 5 trials at span 3, and were therefore assigned a span level of 2. They did however have success on individual trials. Only 1 LI child was unable to successfully complete any trials.

Further investigation found that the response patterns of individual children were consonant with the findings of a group by processing interaction. That is, scores of individual children in the LI group decreased with additional processing demands, while those of children in the NL group did not. Table 3 outlines this finding.

Table 3. Effect of additional processing on the number of trials correct: Number of children in each group who maintained or increased and decreased span when processing demands increased.

<table>
<thead>
<tr>
<th>Group</th>
<th>Maintain/Increase</th>
<th>Decrease score</th>
</tr>
</thead>
<tbody>
<tr>
<td>Language Impaired</td>
<td>6^4</td>
<td>6</td>
</tr>
<tr>
<td>Normal Language</td>
<td>11</td>
<td>1</td>
</tr>
</tbody>
</table>

An error analysis was conducted to ensure that children understood the task and to examine potential group differences in error patterns. Closer investigation of children's errors indicated that only 4 of a total of 110 (3.6%) error trials could be attributed to difficulties in understanding the task. The number of errors made by a child is somewhat tied to continuation criteria, as children who reached a span of level 7 had more

^4 Three of these children were already performing at floor levels on the storage task, so no further decrease was possible with the addition of processing demands.
opportunity to make errors. The number of error trials made by a single child before discontinuation criteria were met ranged from 3 to 6 (M = 4.58, SD = .83). Each trial containing an error was classified as one of 4 types: storage, processing, mixed, or task. In a storage error trial, a child failed to recall at least one word correctly. A processing error trial was evidenced by a word that was incorrectly classified. Mixed error trials included responses with both omissions (storage errors) and miscategorizations (processing error). Finally, in a task error trial, a child failed to re-organize the words for recall, instead pointing back and forth to the two squares as he said each word or failing to point to a size box entirely. Error rates for the two groups are outlined in Table 4, both as frequencies and as percentages-of-total-errors within and across groups.

Table 4. Number (and percentage) of errors in each category made by children in the LI and NL groups on the auditory-verbal processing task.

<table>
<thead>
<tr>
<th>Group</th>
<th>Error Type</th>
<th></th>
<th></th>
<th></th>
<th>TOTAL</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Storage</td>
<td>Processing</td>
<td>Mixed</td>
<td>Task</td>
<td></td>
</tr>
<tr>
<td>Language Impaired</td>
<td>34 (72%)</td>
<td>3 (6%)</td>
<td>6 (13%)</td>
<td>4 (9%)</td>
<td>47 (43%)</td>
</tr>
<tr>
<td>Normal Language</td>
<td>60 (95%)</td>
<td>2 (3%)</td>
<td>1 (2%)</td>
<td>0 (0%)</td>
<td>63 (57%)</td>
</tr>
<tr>
<td>TOTAL</td>
<td>94 (85%)</td>
<td>5 (5%)</td>
<td>7 (6%)</td>
<td>4 (4%)</td>
<td>110</td>
</tr>
</tbody>
</table>

The NL group made more errors overall, however this result is not statistically significant, t(22) = -1.52, p = .14. This result is not unexpected; the NL children achieved higher-level spans and therefore had more opportunity to make errors.

Percentage of storage errors as a function of total errors was compared for the two groups, using arcsine-transformed values to correct for the distributional peculiarities of percentage scores. This group difference proved significant, t(22) = -2.51, p < .02.
Almost all errors made by the NL group could be classified as storage errors, but the LI group showed more diversity in their error patterns.

3.3 Visual-Spatial Working Memory Tasks

The next set of analyses investigated the visual-spatial working memory skills of LI children in comparison with their NL peers to determine whether there were group differences in a visual modality. The analysis strategy for the visual-spatial working memory tasks was identical to that used in the auditory-verbal working memory tasks. Means and standard deviations for span of each group on the two levels of processing in the visual-spatial tasks appear in Table 5. As can be seen, the two groups performed similarly, and span levels for both groups were lower in the task with additional processing demands.

<table>
<thead>
<tr>
<th></th>
<th>Storage M, (SD)</th>
<th>Storage + Processing M, (SD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Language-Impaired</td>
<td>4.50 (1.73)</td>
<td>3.50 (1.62)</td>
</tr>
<tr>
<td>Age-Matched</td>
<td>4.58 (1.73)</td>
<td>3.17 (1.70)</td>
</tr>
<tr>
<td>Both Groups</td>
<td>4.54 (1.69)</td>
<td>3.33 (1.63)</td>
</tr>
</tbody>
</table>

Statistical tests were computed to test the reliability of these findings. Preliminary tests for homogeneity of variance (Levene, p>.05) indicated that this distribution assumption had been met. Therefore, differences between the NL and LI groups on the visual-spatial working memory spans were analyzed using a two-way
mixed model ANOVA with one between subjects factor (Group) and one within subjects factor (Level of Processing).

The ANOVA yielded a main effect of processing, $F = 28.64; \text{df} = 1, 22; p < .02$ such that span was lower for tasks that required additional processing demands. Effect size, measured by partial eta-squared, was .57. There were no significant group differences, $F = .04; \text{df} = 1,22; p > .02$, or interactions between group and level of processing, $F = .85; \text{df} 1, 22; p > .02$. The findings thus do not indicate that the LI group performed differently than their age peers on either of the visual-spatial tasks.

3.4  Comparing Two Domains

The next set of analyses investigated whether additional processing demands influence performance across groups equally in the two modalities. Informal comparison of the modality-specific analyses presented above would suggest that the processing decrements are not the same. In order to make a direct statistical comparison of relative performance across groups on the two modalities, a 3 way ANOVA was completed to investigate the interaction between three variables: one between subjects variable (Group) and two within subjects variables (Modality, Level of Processing). The auditory-verbal and visual-spatial tasks are very different in nature, and it is impossible to know whether, for example, a span of 3 sequentially presented words on an auditory-verbal task is psychologically equivalent to a span of 3 simultaneously presented blobs on a visual-spatial task. For this reason, $z$-score equivalents of span scores were computed based on the NL group’s scores, in order to validly compare span scores across the two modalities. Calculating $z$-scores normalizes the distribution, based on span scores of the NL group,
so that the performance of the LI group relative to this normal baseline can be compared across tasks and domains.

This ANOVA revealed a significant interaction of group by modality by level of processing, $F = 13.43; df = 1, 22; p < .02$. This indicates that relative to the NL group, addition of processing demands in the auditory-verbal modality was more difficult than in the visual-spatial modality. Adjusting for Greenhouse-Geisser and Huynh-Feldt effects in a within-subjects repeated measures design did not change these findings. Effect size, measured by partial eta-squared, was .39. Figure 1 depicts this interaction.

Figure 1. Interaction of group x modality x level of processing on auditory-verbal and visual-spatial working memory tasks.
3.5 Dual Tasks

The next set of analyses addresses children’s ability to integrate and coordinate information from different domains. These two tasks proved to be very difficult for children in both groups. For this reason, results are presented both using span level, and a more fine-grained approach of the number of trials correct. On the coordinating task, 13 children performed at floor levels; on the integrating task, 9 children performed at floor levels. Table 6 outlines group performance on these two tasks.

Table 6: Mean (SD) for span and for number of trials correct in two dual working memory tasks for children with language impairments (LI) and normal language (NL)

<table>
<thead>
<tr>
<th></th>
<th>Coordinating</th>
<th>Integrating</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Span</td>
<td>Trial</td>
</tr>
<tr>
<td>Language-Impaired (LI)</td>
<td>2.42 (.67)</td>
<td>2.33 (2.42)</td>
</tr>
<tr>
<td>Normal Language (NL)</td>
<td>2.92 (1.00)</td>
<td>4.33 (3.31)</td>
</tr>
<tr>
<td>Both Groups</td>
<td>2.67 (.87)</td>
<td>3.33 (3.02)</td>
</tr>
</tbody>
</table>

Table 7 shows the number of children at higher and lower span levels in the two dual tasks. In both tasks, more children in the NL group were able to achieve a span of 3 or greater. Due to the limited variance on this task, one cannot assume a normal distribution so parametric tests were not warranted. Therefore a non-parametric analysis of this data was completed. The nature of these procedures was such that it was necessary to look first for group effects, then for task effects.
Table 7: Number of SLI and NL children at and above span floor performance on the coordinating and integrating tasks.

<table>
<thead>
<tr>
<th></th>
<th>At Floor (Span of 2)</th>
<th>Above Floor (Span 3+)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Coordinating</td>
<td>Integrating</td>
</tr>
<tr>
<td>Language-Impaired (LI)</td>
<td>8</td>
<td>7</td>
</tr>
<tr>
<td>Normal Language (NL)</td>
<td>5</td>
<td>2</td>
</tr>
<tr>
<td>Both Groups</td>
<td>13</td>
<td>9</td>
</tr>
</tbody>
</table>

A Fisher exact Test found no significant group differences on the coordinating task, $p > .05$; but a significant group difference on the integrating task, $p < .05$ was observed. Significantly more children in the NL group than in the SLI group achieved some degree of success on the integrating task. Analysis of the trial data yielded similar findings.

Across both groups of children, how do the coordinating and integrating tasks compare? As can be seen in Table 8, more children overall were able to achieve a span above floor levels on the integrating task than the coordinating task. Children found it easier to remember information when it was presented in an integrated way, where each auditory stimulus was matched sequentially with a visual stimulus, than when the two sorts of information were presented in a less coordinated fashion, (i.e. the auditory information in temporal sequence and the visual-spatial information all at once). In order to further investigate this trend, number of trials correct, a more sensitive dependent variable, was used. By using number of trials correct as the dependent variable, there is greater variance in scores, and children are given some credit for correctly answering one or two trials correctly even if they failed to achieve a span of 3. As was seen in the prior analysis of the span data, the number-of-trials data indicated that children were more
successful in the integrating than in the coordinating task. In the coordinating task, children obtained a mean of 3.33 (SD = 3.02, Range = 0 - 11) trials correct. In the integrating task, children obtained a mean of 4.33 (SD = 3.40, Range = 0 – 13) trials correct.

A non-parametric Wilcoxon Matched Pairs Test was used to test the significance of this group difference. This test showed reliable differences between the two tasks, T = 48.50; Z = 2.32; p < .05. The same test with span as the dependent variable was not significant, T = 3.5; Z = 1.77; p >.05.

3.6 Correlating Working Memory and Language Skills

The final set of analyses investigated the correlations between working memory and narrative abilities. To investigate these relationships, correlations between scores on the auditory-verbal processing task and the oral narration tasks were examined followed by correlations between visual-spatial processing and oral narration. In the working memory tasks, group differences were most significant in the auditory-verbal task that required processing of the items. In addition, intuitively this is the task that most resembles the demands of real language and requires both memory and manipulation of words. For these reasons, scores on this auditory-verbal processing task were used as an indicative measure of verbal working memory. To parallel this analysis in the visual-spatial modality, scores on the visual-spatial processing task were used for further correlations.

Two scores were chosen to represent narrative abilities on the TNL: 1) total raw score for the 3 oral narration (ON) subtests, and 2) raw score for the Alien (single
picture) subtest. The 3 ON subtests measure diverse expressive narrative skills: story retelling, creation of a narrative from a picture sequence, and creation of a narrative from a single picture. These 3 tests increase in difficulty, and together can be a measure representing the diverse requirements for successful narrative production in a variety of conditions. The raw score on the Alien subtest represents the most challenging narrative task. Children were given a single picture and asked to create a story. Without the support of structure provided by a sequence of pictures, many children found this task particularly difficult, and there was great diversity in the raw scores. Production scores, not comprehension scores, were analyzed because inclusion in the LI and NL groups was operationally defined using expressive, not receptive, language scores.

As can be seen in Table 8, the SLI group achieved lower raw scores on the oral narration sections of the Test of Narrative Language. The following analyses will explore how these scores relate to working memory abilities in both auditory and visual modes.

<table>
<thead>
<tr>
<th>Total Oral Narration</th>
<th>Alien Subtest</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean (SD)</td>
<td>Range</td>
</tr>
<tr>
<td>Mean (SD)</td>
<td>Range</td>
</tr>
<tr>
<td>Language Impaired (LI)</td>
<td>30.73 (11.42)</td>
</tr>
<tr>
<td>Normal Language (NL)</td>
<td>51.33 (12.93)</td>
</tr>
</tbody>
</table>

Frequent ties are inherent in data measuring span, therefore a non-parametric analysis of the data was conducted using a rank order Gamma correlation. For the two groups taken together, there were significant correlations between span on the auditory-verbal processing task and both the raw scores on the ON subtests ($r = .62$, $p < .05$) and
the alien subtest \( r = .65, p < .05 \). These values indicate a good probability that scores will be similarly ordered in the two domains.

The significant correlation between the measures of narrative production and auditory-verbal processing is perhaps not surprising, given that half the children are language-impaired and scored very poorly on the narrative tasks. This resulted in an unusually large distribution of narrative scores. In order to further explore this correlation, the language-impaired children were excluded, and the analysis was repeated. With only the NL children included in the analysis, the gamma correlations between auditory-verbal processing tasks and the ON subtest \( r = .77, p < .05 \) and the alien subtest \( r = .75, p < .05 \) both remained significant and the probability for similar ordering of scores in the two domains actually increased.

Narrative and working memory data were available for a further 9 NL children not included in the core group of children for this experiment, because they were not matched to children in the LI group. They all met inclusionary criteria for the NL group. In order to increase the power of analysis, scores for these children were also included; thereby creating a group of 21 children whose language is within the normal range for the correlation analysis. The correlations between the auditory-verbal processing task and ON subtests again proved significant \( r = .61, p < .05 \), however, there was no longer a significant correlation between the alien task and auditory-verbal processing. Again, the analysis indicates the good likelihood that scores in the two domains will be similarly ordered.

Are the correlations between working memory and narratives scores found above modality specific? To answer this question, one final analysis investigated the
correlations between visual-spatial working memory and narrative scores (ON scores, alien subtest scores). The Gamma correlation between visual-spatial processing and both ON scores and alien subtest scores proved non significant in the original group of 12 NL and 12 LI children. This is perhaps not surprising given that the LI children showed a strong dissociation between visual-spatial and verbal skills. For this reason, the correlation between visual-spatial processing and narrative performance was further explored first in the group of 12 NL children, then in the larger group of 21 NL children. There were no significant correlations between visual-spatial processing and narrative production in the small group of 12 NL children; however a significant relationship between the alien subtest and visual-spatial processing ($r=.52$, $p<.05$) emerged in the larger group of NL children. This finding provides some evidence for a relationship between visual-spatial processing and narrative production skills, but these results need replication.

Overall, these results suggest a relationship between verbal working memory, as measured by the auditory-verbal processing task, and narrative production. Six tests of the underlying relationship between auditory-verbal processing and text creation were undertaken and 5 proved to be significant. The cumulative binomial probability that 5/6 correlations would prove significant on the basis of chance alone is .11. Given the importance of the issues and the fact that few other studies on this topic have been conducted, this value seems acceptable. There is certainly support here for further investigation of the relationship between auditory-verbal working memory and narrative production. Findings for visual-spatial working memory were somewhat equivocal,
although reliable links to narrative scores for the most difficult task were demonstrated for the larger group of NL children.

3.7 Summary of Results

1. **Auditory-Verbal Working Memory:** The LI group achieved lower spans on the auditory-verbal task than the NL group. There was a significant group by level of processing interaction, such that children in the LI group performed more poorly on the task that required processing relative to the task with only storage demands.

2. **Visual-Spatial Working Memory:** There were no significant group differences on the visual-spatial tasks. Span for both groups decreased significantly when processing demands were added.

3. **Working Memory across Modalities:** There was a significant interaction between modality, level of processing and group, such that the LI group showed difficulty when processing demands increased relative to their peers, but only in the auditory-verbal modality.

4. **Dual Tasks:** Both groups performed similarly on the coordinating tasks; however, there was a significant difference in group performance on the integrating task. Both groups attained higher spans on the integrating than coordinating task. Findings from this analysis must be interpreted with caution because many children performed near floor levels.

5. **Working Memory and Narratives:** The results suggest a relationship between working memory (specifically the auditory-verbal processing task) and narrative production (specifically the ‘alien’ single picture storytelling task and the 3 oral
narration subtests) both when including all subjects in the analysis and when considering only the children with normal language skills. The relationships between visual-spatial working memory and narrative skills remain less clear.
4 Discussion

The purpose of the current study was to examine two functions attributed to the central executive (the coordination of storage and processing demands and management of information from different modalities) in both typically developing and language-impaired children. In addition, the relationship between working memory and narrative production was explored. In the following discussion, the primary results of this study are presented with reference to the current research literature. Then, considerations for future research and clinical implications are discussed.

4.1 Storage and Processing in two Modalities

4.1.1 Summary of main finding

The first goal of the current study was to investigate whether children with SLI have success equal to their age-matched peers on working memory tasks, particularly when processing demands are high. The data suggest three important answers to this question. 1) In the auditory-verbal domain, the children with SLI were less able to manage the complex storage and processing demands of working memory than their peers with typical language. Group differences were more evident in the task that required processing and storage than in the task that required storage only. 2) In the visual-spatial domain, no group differences were found, suggesting that the children with SLI performed equally to their peers. 3) Direct comparison of the two domains indicated that relative to age peers, children with SLI experience difficulty in auditory-verbal but not visual-spatial processing. There are at least two possible explanations for these data.
Children with SLI might have a deficit that is specific to language, or alternatively, and despite the apparent relative strength of the visual-spatial domain, visual processing difficulties might still exist but only be seen in a more complex task. Before evaluating these two possible explanations, the current findings will be compared to the larger literature.

4.1.1.1 Previous auditory-verbal research

Ellis Weismer et al. (1999) and Montgomery (2000a, 2000b) recently explored auditory-verbal working memory in children with SLI. Results from both researchers support the current findings that children with SLI perform more poorly than their peers on auditory-verbal working memory tasks and that the greatest differences between language-impaired and typically developing children emerge when the task requires both processing and storage.

Ellis Weismer et al. (1999) measured auditory-verbal working memory with a task that was significantly different from the task in the current research, but shared the characteristic of requiring both processing and storage. Children verified whether simple sentences were true or false (processing) and remembered the final word of each sentence. Span of the SLI group was significantly less than span of the age-matched peer group. This evidence provides converging evidence that children with SLI experience difficulty in managing the demands of processing and storing auditory-verbal information.

The tasks in the current study were derived from Montgomery (2000a, 2000b), and were therefore similar in nature. Overall, Montgomery's research findings are similar to the current findings, but two significant differences between Montgomery's
research and the current study warrant further discussion. The children in Montgomery’s (2000a, 2000b) studies achieved higher spans than those in the current study across all the auditory-verbal working memory tasks. In addition, Montgomery found no group differences when processing demands were low or minimal. Group differences emerged only in the second-level processing task, where children were required to classify the words by semantic category and then organize them by size of referent within each semantic category. In the current study, although group differences were greater on the storage + processing tasks, differences nonetheless existed even at the level of simple storage.

Differences in task presentation and scoring could account for the disparity in overall spans and performance patterns across tasks. Children in Montgomery’s (2000a, 2000b) studies completed a large number of demonstration and practice trials and a pre-test prior to the experimental trials. Only children who successfully completed 6 of 8 trials on the pre-test continued to the experimental trials; Montgomery (2000a) does not state how many children were excluded because they failed to meet pre-test criteria. Very low performers would have been excluded from the analysis, thereby raising the group mean. Children no doubt learned from the task exposure during this initial testing phase and thus achieved higher spans overall.

Additionally, in contrast to the current study, children in the Montgomery studies were given the option to have any word list repeated before recall. Criteria for span was also significantly lower (2/3 trials correct in Montgomery, 3/4 trials correct in the current study). The final difference in tasks was the order of list presentation. In the current study all children began at span 3 and systematically increased until failure. In
Montgomery, children attempted all span levels in a random order. Each of these task and scoring differences might contribute to the inconsistencies in absolute span levels between Montgomery (2000a, 2000b) and the current study. The overall finding that SLI children perform auditory-verbal working memory tasks more poorly than their peers when processing demands are high is consistent in all studies.

4.1.1.2 Previous visual-spatial research

Reggin (2002) and Ellis Weismer (2002) have both studied visual-spatial working memory in children with SLI. Reggin’s (2002) task only tapped storage capacity. Her finding, that children with SLI evidence no significant difficulty in the storage of visual-spatial information, is replicated in the current study. Ellis Weismer’s (2002) task was significantly different from the tasks used in the current study; however, it shared the important characteristic of balancing processing and storage demands.

Contrary to the current findings, the SLI children in Ellis Weismer (2002) were able to store less visual-spatial information than their peers when performing a simultaneous processing task. One difference that might account for this seemingly contradictory finding is the age of participants. Ellis Weismer (2002) studied working memory in a group of adolescents with language impairments; the children in the current study ranged in age from 7-11 years. Johnston (1994) reviewed research examining cognitive deficits in SLI children, namely, in symbolic play and conceptual development. She suggests that language is essential to normal cognitive development, so children with poor language skills will inevitably begin to show cognitive deficits. Cognitive deficits would increase with time, such that we might expect teenaged children with SLI to evidence greater cognitive deficits than younger children with SLI. Memory strategies
are one area of cognition that develop over the school years. Delays in this domain could explain Ellis Weismer’s (2002) finding of a visual-spatial working memory deficit. Reggin (2002) provides some insight into the use of memory strategies for visual-spatial information by children with SLI. Although Reggin’s SLI group did not reliably differ from their age peers, they did achieve somewhat lower spans on the visual-spatial storage task. In her discussion of this point, Reggin notes that different memory strategies between the LI and NL groups could account for this trend. Based on the comments of some of her NL participants, she argues that the NL group in her study might have used verbal coding strategies to assist in encoding the visual-spatial information and thereby have earned higher scores than the SLI group. She notes for example that some children assigned numbers to the filled squares in each row, and others labelled the gestalt patterns formed by the filled squares, “it looks like an arrow.”

Great care was taken in the creation of the grids for the current study to exclude patterns that were easy to encode verbally. Clearly, this change was important. Although the storage task used in this study was a virtual replication of Reggin’s task, the trend of SLI children achieving lower spans was not replicated. In Ellis Weismer’s task, the storage requirement was to remember the location of a specific item in a grid containing only 3 squares. This information could be easily encoded verbally (i.e. top, middle, bottom). Keeping in mind the advanced age of her subjects, it is seems possible the NL children in Ellis Weismer’s study were also using such a verbal strategy, thereby enhancing their visual-spatial memory span relative to the LI group. If so, the apparent visual working memory deficits that she reports would in fact be due to differences in verbal skills, and her findings would no longer contradict those in the current study.
The final finding, comparing processing across domains, is difficult to compare to current literature because no previous research has directly compared auditory-verbal and visual-spatial working memory in children with SLI. Overall, the findings of the current study seem to be largely in accord with the current research literature. Once task and subject pool differences are considered, there is no clear contradiction between this study and others. Children with SLI experience difficulty managing the balance between processing and storage in the auditory-verbal domain only. Although further research will be important for a thorough understanding of the nature of differences between studies, sufficient evidence exists to justify an interpretation of the current results.

4.1.2 Implications for SLI

There are two possible aspects of the current findings that have bearing on our understanding of SLI: the absence of group differences on the visual task, and the decline in span on auditory-verbal tasks as processing load increased. Let us consider each in turn.

The first possible explanation of the lack of group difference on visual-spatial tasks is that children with SLI do experience difficulty with only auditory-verbal processing. This interpretation fits the facts but is difficult to reconcile with the larger literature exploring visual-spatial processing in LI children.

Visual-spatial processing and storage are often viewed as relative strengths of children with SLI, but at least three studies have found evidence for visual-spatial processing deficits (Tallal, Stark, Kallman, and Mellits, 1981; Miller et al., 2001; Johnston & Ellis Weismer, 1983). These studies raise the second possibility: that children with SLI do have visual-spatial processing limitations but that they are either 1)
of a lesser severity than those seen in the auditory-verbal domain, or 2) restricted to the processing of temporal sequences.

Mental rotation tasks would seem to require more complex ‘calculations’ than the simple sorting task used in the current study. Children must hold the image in mind and transform it before solving some additional assessment of its properties. Several studies have indicated that SLI children perform more poorly than age peers on rotation tasks. Miller et al. (2001) included visual search and mental rotation tasks in a large study of response times of SLI children to tasks that are both linguistic and non-linguistic in nature. Children with SLI performed more slowly than their peers in both the visual search and mental rotation tasks, thus suggesting a processing deficit in the visual-spatial domain.

Johnston and Ellis Weismer (1983) provide further evidence that an auditory-processing account may not be sufficient to explain SLI with data from a mental rotation task. They found that children (aged 6 and 9 years) with SLI were slower to judge whether two rows of geometric shapes were the same. These findings cannot simply be set aside as further evidence of failure to use verbal memory strategies. Rotation tasks can explicitly indicate whether verbal or imagistic strategies are being used. A linear function between degree of rotation and response times indicates imagistic strategies, and both the NL and the LI group in Johnston and Ellis Weismer (1983) used such strategies in solving the rotation problems.

Savich (1984) explored the skill of anticipatory imagery in language-impaired children. Anticipatory imagery is defined as “a representational ability that requires prediction of future changes in form or position of an object” (Savich, 1984, p. 494), and
is necessary to complete a mental rotation task. Savich (1984) found that the children with SLI performed less accurately than their age-matched peers on 5 measures of anticipatory imagery. On one such measure, children were required to anticipate the movement of a snail along a path. Another measure asked children to watch the experimenter fold a piece of paper and then anticipate where it would be creased. Savich (1984) used these findings to argue that a relationship exists between anticipatory imagery and language ability. This body of research is thus compatible with the view that the present study would have found visual-spatial limitation if the tasks had required more demanding processing.

Equally plausible is the possibility that it was the simultaneous nature of the visual-spatial stimuli that led to group similarities. One important difference between the auditory-verbal and visual spatial tasks in the current study is the temporal difference in stimulus presentation. The visual-spatial tasks present information simultaneously, while the auditory-verbal tasks present information sequentially. The data could be interpreted to suggest that group differences do not result from the modality differences on the tasks, but rather the temporal differences.

Tallal et al. (1981) provide early evidence that children with SLI do evidence temporal processing deficits that extend beyond the auditory domain. In this study, children were trained to associate each of 2 stimuli (either auditory – complex tones or visual – nonsense letters) with a response button. The stimuli were then presented in rapid succession, and children responded by pushing the appropriate sequence of buttons to correspond to what they had seen or heard. Results suggested that children with SLI made more errors than their peers on both the auditory and visual tasks. In addition, the
relative impairment of the auditory modality was greater in the older (7-8 year-old) than younger (5-6 year-old) children. Again, note that the nature of the stimuli makes it unlikely that these findings simply reflect a failure to use verbal memory strategies.

In summary, while findings from the present study seem to indicate that children with SLI have working memory deficits only within the auditory-verbal domain, this conclusion would be premature. The larger literature indicates that children with SLI could have visual-spatial processing limitations that are either 1) of a lesser severity than those seen in the auditory-verbal domain, or 2) restricted to the processing of temporal sequences. Given the nature of the tasks used in the present study, the data can neither confirm nor disconfirm this alternative explanation.

Further research will be needed to reconcile the differences in findings regarding visual processing in children with SLI, and it is important to do so. These findings have implications for the larger picture of understanding the nature of specific language impairment. Windsor (2002) contrasts two hypotheses regarding the underlying deficit in SLI: specific and generalized processing deficits. Findings of a deficit in visual processing in addition to a deficit in auditory processing would support a generalized processing deficit hypothesis. If the findings of the current study, that children with SLI do not evidence visual-spatial processing deficits, were replicated even with more complex visual tasks, this would provide support for the view that the deficits underlying SLI are restricted to the auditory domain.

We return now to the second finding that has bearing on our understanding of SLI: the decline in span on auditory verbal tasks as processing load increased. This finding is unsurprising and supported by the larger literature. Both Montgomery (2000a,
2000b) and Ellis Weismer (1996) had similar findings using tasks that tapped verbal working memory. What can explain the poorer performance of the SLI children on the auditory-verbal processing task? Montgomery (2000b) outlines potential explanations for the finding that children with SLI showed a decrease in performance as processing demands increased on his working memory tasks: semantic knowledge, storage differences, and managing dual demands. Given the similarity of Montgomery's (2000b) working memory tasks to the auditory-verbal working memory tasks used in the current study, the explanations are relevant.

The first possible explanation of the finding that the span levels of the children with SLI decreased relative to their peers as processing demands increased is that children with SLI have poorer semantic knowledge and semantic processing skills (Montgomery, 2000b). This explanation is inadequate to explain the results of the current study for two reasons. First, the words used in this task were chosen using stringent selection criteria to facilitate easy lexical access. All the chosen words are typically learned by age 3, so even the SLI children who are delayed in lexical access should have had sufficient time to learn the words and form robust representations. Secondly, all children were able to successfully categorize at least 23 of the 26 words during the pre-test. Errors in this pre-test were minimal, and occurred among children in both groups. There were no group differences in the pre-test to indicate that the children with SLI found the categorization task more challenging than their peers.

A second explanation is that storage differences might account for the decreased performance of SLI children relative to their peers. For example, Edwards and Lahey (1998) suggest that children with SLI have difficulty forming accurate phonological
representations and that this may be the source of low performance on non-word repetition tasks. Other potential differences in storage are verbal rehearsal and articulatory planning deficits (Gathercole & Baddeley, 1990b). At first, it appears easy to discount explanations that appeal to storage differences. Although such a deficit might explain overall decreased performance of the SLI children relative to their peers, it is less able to explain the specific decrement on the processing task given that storage demands were equal on both tasks.

Caution must be used in immediately rejecting these first two possible explanations for the current finding because although the processing of semantic information and storage of information may not pose a difficulty when performed independently, the trade-off between storage and processing in a limited capacity system must be considered.

Although the children with SLI evidenced knowledge of the required semantic skills to successfully complete the task, they might have used this knowledge less efficiently given the demands of simultaneously storing and processing information. This explanation appeals to a Just and Carpenter (1992) model of working memory where trade-offs between storage and processing demands remain central. If processing were less efficient among the children with SLI, it would consume a larger amount of available resources, thereby leaving fewer resources to allocate to storage. In addition, if storage were less efficient, it would consume larger amount resources. Error patterns provide evidence for this claim. When processing demands increased, across groups, almost all errors were related to storage. Children forgot words when given the difficult task of categorizing them before recall. This explanation is supported by McGregor, Newman,
Reilly and Capone’s recent study (2002) showing that when SLI children had difficulty remembering a word, they also had difficulty drawing its referent – a finding that suggests that less rich semantic representations do lead to poor processing.

Of the three possible explanations for the reduced spans observed in the current processing task, the one suggesting that inefficiencies in processing impact storage when both are performed simultaneously provides the most convincing account of the data. A number of recent studies have explored the processing inefficiencies of children with SLI (e.g. Miller et al., 2001; Gillam et al., 1998). An important future direction for research will be to investigate the results of these processing inefficiencies when combined with storage demands, which is a common feature of real life language processing.

4.1.3 Implications for models of working memory

The findings of a selective impairment in auditory-verbal processing in children with SLI informs 3 current issues in working memory: modularity of the working memory system, balance of storage and processing, and the value of the central executive. Baddeley’s (1986) model suggests a very modular system of working memory. His model has two slave systems (the phonological loop and VSSP) to support storage of information from different modalities. This model predicts a possible dissociation between one’s ability to store auditory-verbal and visual-spatial information. The findings from this study could be taken to support such a dissociation; children with SLI were impaired in the storage of auditory-verbal but not visual-spatial information.

Just and Carpenter (1992) focus on the importance of using tasks that require both processing and storage to measure individual differences in working memory. Daneman and Merikle (1996) provide experimental evidence to support this claim in their meta-
analysis of working memory studies. Thirty-eight studies correlated verbal working memory (using a task that required both processing and storage) to general measures of comprehension, with an average weighted effect size $r = .41$. Twenty-five studies examined the same correlation with a task that required storage only (weighted effect size, $r = .28$). The current study likewise supports the importance of considering the tradeoff between storage and processing when measuring working memory. Group differences in span were most evident in the complex task that required both auditory-verbal processing and storage.

A final issue within working memory that was addressed by this study is the value of the concept of the ‘central executive’. Baddeley (1986) suggests that processing occurs in the central executive. Supporting this claim, Duff (2000) contrasts a dual task requiring storage with a dual task requiring processing to support this claim. A group of adults completed an auditory-verbal (digit recall) and a visual-spatial (modified Corsi-blocks task) storage task separately (in a single task paradigm) and simultaneously (in a dual task paradigm). Results between the single and dual presentations were compared, and no reliable differences were found. Apparently the participants were able to “add” storage loads from another modality without cost. This evidence supports the separation of storage resources in working memory. In contrast, when two processing tasks (auditory-verbal – lexical decision, visual-spatial – respond to moving target) were completed in single and dual task paradigms, there were significant differences. Performance on the visual-spatial task declined significantly relative to single task performance in a dual-task paradigm. Duff (2000) interprets these results to suggest that
a shared pool of resources in the central executive supports processing in both modalities. The current study would seem to provide evidence to counter this claim.

If a single pool of processing resources exists in the central executive, it should uniformly support processing of both auditory-verbal and visual-spatial information. The results of the current study, however, suggest that for children with SLI, processing resources are not equivalently affected in both modalities. Relative to their age peers, children with SLI evidenced a deficit in processing of auditory-verbal but not visual-spatial information. Further clarification is needed to explain how one pool of resources might differentially support processing in different domains. This differentiation challenges the validity of a central executive.

In summary, the current finding of a selective impairment of auditory-verbal processing in children with SLI does not rule out the possibility that visual-spatial processing deficits do exist. Further research to separate temporal and modality differences is needed. However, if indeed children with SLI do evidence processing difficulties only in the auditory-verbal domain this would provide support for a modular view of working memory, and call into question the validity of the notion of a central executive. In either case, the current findings point to the importance of using complex tasks to measure working memory.

4.2 Dual Tasks

4.2.1 Summary of main finding

The dual tasks were extremely difficult for all children in this study. For this reason, caution must be used when interpreting the results. In these tasks, children were
required to coordinate unrelated information from the auditory-verbal and visual-spatial modalities or integrate information from the two modalities into one single representation. Using non-parametric statistics, there were two main findings: 1) the integrating task was easier than the coordinating task for all children, and 2) there was a group difference in the integrating, but not coordinating tasks. First, these findings will be compared to the larger literature, and then I will speculate about the reasons for the current findings.

4.2.2 Previous dual task research

The differences between tasks that require integration and those that require coordination have not been previously explored in children, thus it is not possible to compare the results directly to previous findings. The relative difficulty of the coordinating task is somewhat surprising, given that intuitively, the integrating task requires one processing element more than the coordinating task. In both tasks, children must encode and recall words and locations. In the integrating task, children must also associate each word with a location. Although comparing the relative difficulty of integrating and coordinating tasks in adults was not the aim of the study by Emerson et al. (1999), the reported mean response times suggest that adults also find coordinating more difficult than integrating (e.g. 'easy' condition RT: integrating $M = 3801$ms, coordinating $M = 4454$ms). In both tasks participants watched two 'ships' move across a screen at different rates and had to decide which 'ship' would win the race. In the integration task they simultaneously listened to sentences that were related to the outcome of the race (e.g. The black ship will not arrive before the white ship) and had to verify the truth of these sentences. In the coordination task, participants were again
required to verify sentences simultaneous to the visual 'ship' race task, however now the sentences were unrelated (e.g. May does not come before June). Although the tasks were different in nature, the findings converge with those in the present study. Thus the preliminary finding that coordination is more difficult than integration cannot be supported by literature with children, but is suggested by the adult literature.

The only study to explore coordination abilities in SLI children relative to their peers is Reggin (2002). Again converging on the current findings, she found no group differences between LI and NL children on a task that required coordination of information from different modalities. The performance of SLI children relative to their peers on integration has never been examined; therefore it is impossible to compare the current results that children with SLI are less successful at integrating information from different modalities than their peers to other studies.

The replication of these results will be an important first step in future research, however it remains interesting to speculate about the nature of the task differences that might explain the differential performance across tasks and groups, and the implications of these differences for working memory and SLI.

4.2.3 Implications for working memory

The coordinating and integrating tasks explore the role of the central executive proposed by Baddeley (1996) of allocating resources across modalities. Both tasks required the same amount of storage; so any differences between tasks could be attributable to different central executive, not slave system, demands. Lower performance on the coordinating task could result from higher demands on the central executive resources. Higher performance on the integrating task could result from lower
central executive demands. Examination of the differences between the two tasks can help outline exactly what functions are taxing to the central executive. This analysis suggests four features of the integrative task that may have affected performance: 1) the potential for use of bootstrapping from visual to auditory-verbal spans, 2) the temporal-sequential nature of the stimuli, 3) the reduced wait time prior to a response, and 4) the focused attention.

One possible explanation for the higher scores on the integrating task emerges from observations of children during the study. The auditory-verbal part of the task might be being bootstrapped by the visual-spatial part of the task. In a bootstrapping process “one type of information acts as a ‘bootstrap’ which helps children get ahold of another type of information” (Chiat, 2000, p. 30). Span on the tasks in different modalities is not psychologically equivalent. Among all children, the highest span on the auditory-verbal storage task was 5. The highest span on the visual-spatial storage task was 7. Eighteen children achieved visual-spatial storage spans that were greater than their auditory-verbal storage spans. Only 3 children evidenced the reverse pattern, earning an auditory-verbal score that was greater than their visual spatial span. The remaining 3 children achieved the same span on both tasks. Presentation of the auditory-verbal and visual-spatial tasks together, such that each word had a corresponding location, might have enabled children to use their strong visual-spatial working memory to assist recall of the words. For example, at a span of three, if a child were able to remember three locations, but only two words, he might be more aware that a word is missing, and then try again to retrieve it. Comments by children (e.g. “I know there’s one more word”) indicated that some children were using such a strategy.
A second explanation focuses on the temporal characteristics of the stimuli. The presentation of the auditory-verbal stimuli is identical in both dual tasks, but the visual-spatial presentation differs. In the coordinating task, visual-spatial stimuli presentation is static, matching that in the visual-spatial storage task. In the integrating task, presentation is sequential and dynamic. One square fills in synchrony with the presentation of one word. This changes the nature of the visual task and gestalt processing of the pattern becomes a less effective strategy. Instead, each individual square must be encoded as it fills. Although this may have disadvantaged children who relied on imagistic strategies in the coordinating task, this disadvantage was apparently balanced by the advantage of processing and remembering information with similar rather than dissimilar temporal properties.

In addition to these temporal effects on encoding, temporal factors also affected responses. In both the integrating and coordinating tasks, verbal response begins 500ms after the final stimulus presentation. In the integrating task, the spatial pointing response occurs simultaneously to the verbal response. However, in the coordinating task, the pointing response begins only after completion of the verbal response (at least 3500ms). Reggin (2002) found that simply increasing the length of time a child must hold visual-spatial information in working memory before responding leads to a decrease in span. Towse, et al. (1998) suggest that retaining information in a storage system requires some amount of processing resources, such that it is important to consider not only the processing and storage demands, but also the time required. Perhaps the delay before the pointing response accounts for task differences observed in the current study.
Finally, there are differences in the types of attention required to successfully complete the coordinating and integrating tasks. Both tasks are demanding of attention and necessitate focussed attention. The coordinating task also calls for attention to be divided or to switch rapidly between unrelated stimuli. Intuitively the coordinating task appears more attention demanding than the integrating task; this could be one final source of performance differences between the two tasks.

Further research is needed to understand the nature of complex processing tasks that entail information from multiple sources. Baddeley (1996) suggests that one role of the central executive is to manage information arriving from different modalities. Exactly what this entails has not yet been investigated. Emerson et al. (1999) recommend relating this “dual-task overhead” (Duff, 2000, p. 15) to other cognitive functions that have been studied more extensively (i.e. attention switching). Contrasting different types of dual-tasks (i.e. integrating and coordinating tasks) will further delineate the component functions required for successfully managing information from different modalities. For example, increased temporal demands may be inherent in ‘coordinating tasks’, and if so, other studies should find similar performance differences. Further examination of how strategy and time relate to central executive functioning is warranted.

4.2.4 Implications for SLI

As discussed in relation to the findings of processing difficulties in the auditory-verbal domain, the themes of temporal processing and memory strategy also pertain to our understanding of SLI. Following the argument from the previous section, success on the integration task entailed the simultaneous processing of sequential stimuli in two modalities, and perhaps also the effective use of visual-spatial memory to assist in
auditory-verbal memory. These are two areas that seem ripe for further exploration as we attempt to understand the deficits underlying SLI.

Windsor (2002), when contrasting specific and generalized processing accounts of SLI has argued for the importance of considering task domain. The current study extends the argument further. Not only is it important to consider task domain, but one must also think about combining information from different domains, and the ways in which such combinations may be handled. Although there has been considerable work on lower level perceptual processing of sequential stimuli in single modalities, particularly by Tallal and her associates (Tallal et al., 1981), there has not been equivalent work with more complex combinations. The recent report by Gillam, Hoffman, Marler, and Wynn-Dancy (2002) suggests that further studies on this topic will be fruitful.

4.3 Linking Working Memory and Narrative Production

4.3.1 Summary of main finding

Exploration of the relationship between working memory and narrative production yielded two interesting findings: 1) an auditory-verbal working memory task that requires both processing and storage correlates with narrative production, and 2) auditory-verbal working memory is a stronger predictor of narrative skill than visual-spatial working memory, although significant correlations were found in both modalities.

The relationship between auditory-verbal working memory and narrative production has only been previously explored by Pontin (2002). She found a significant negative correlation between auditory-verbal working memory and one aspect of narrative production, i.e. number of nongoal statements, in 5-year-old children. The
The current study extends this finding to an older population (7-11 year-old children) and a wider measure of narrative that considers a diverse range of skills including causal and temporal relationships, clarity of reference, grammaticality, creativity, completeness and coherence. The current research concurs with Pontin’s findings to suggest that narrative production is influenced by auditory-verbal working memory.

The relationship between visual-spatial working memory and language skill has not previously been studied in children. Shah and Miyake (1996) investigated how visual-spatial and auditory-verbal working memory predict different complex cognitive tasks (including language skills) in adults. They found no significant relationship between visual-spatial working memory and language skills. The current study did find some evidence for such a relationship in children. This finding requires replication. Although research investigating the link between working memory and narrative production is limited, the literature that does exist seems in accord with the current findings. The next step is to consider the implication of these findings for our understanding of working memory and of SLI.

4.3.2 Implications for models of working memory

The finding of a correlation between working memory and narrative production could be explained in two ways: 1) both the narrative and working memory tasks simply tap the same language processing skills, therefore the correlation is unsurprising or 2) the ability to store and process information independent of modality is needed to successfully produce narratives.

Daneman and Merikle (1996) criticize span measures of auditory-verbal working memory and claim it is unsurprising that spans predict language skills given that success
on span tasks requires language processing. The correlation between auditory-verbal working memory and narrative production in the current study could be subject to the same criticism. However, there are at least two reasons to reject this argument. Firstly, the auditory-verbal tasks require language processing only at the single word level. In contrast to traditional span tasks used by Daneman and others, the measure used here does not require processing of sentences. In this way it is more representative of a memory task than a language (sentence) processing task. Secondly, visual-spatial processing also correlated significantly with narrative production. Unlike other tasks that have been used to assess working memory outside the language domain, (i.e. math span task; Turner & Engle, 1989), the visual-spatial processing task was non-verbal. Thus evidence from the current study discounts this criticism that the correlation is simply an outcome of the language processing required by both tasks.

Given that a correlation does exist between the construct of working memory and narrative production, further research is needed to understand the connection. Baddeley et al. (1998) suggested that the phonological loop is only relevant to language learning, not to language use and he and his team have offered little further comment on how other components of his model might influence language learning or use. The current findings certainly suggest that their conclusions about language use may have been premature, perhaps reflecting his earlier reliance on storage tasks. Moreover, the suggestion of a relationship between visual-spatial working memory and narrative production provides initial evidence that components other than the phonological loop might be relevant to language production. Further exploration is needed to explore these connections, especially research with working memory tasks that are independent of language.
This finding of a relationship between working memory and language is important. The working memory literature sometimes seems artificial and removed from real-life language, but this study provides clear evidence for a relationship, thus validating the construct of working memory. The details of the connection now warrant continued investigation.

4.3.3 Relevance to SLI literature

In agreement with findings by Montgomery (2000a) and Ellis Weismer et al. (1999), the current study provides evidence for an explicit relationship between working memory and language. The current finding extends the relationship from morpheme and sentence level language to narrative production, a higher-level, complex aspect of language. This result is particularly interesting because narrative planning, and more broadly text planning, is one of the major developmental achievements of the school years, and a critical skill for school success. It is also an area in which school age children with SLI are known to have difficulty.

In typically developing children, narrative development is well underway by kindergarten age. However, many significant improvements in narrative skill do occur during the school-aged years (Nippold, 1998). Nippold (1998) suggests that with age, children tell stories that are longer, more detailed and more clearly organized. Stein and Glenn (1979) compared the story-retelling skills of 6 and 10-year-old children. They found that the older children recalled more total idea units than the younger children.

Narrative planning is an extremely challenging task that requires both storage and processing of information. Rispoli and Hadley (2001), in a study of spontaneous language samples of preschool-aged children, suggest that language breakdowns occur at
the “leading edge” of a child’s competence. Given that narrative planning seems intuitively to be extremely demanding on working memory, it is unsurprising that narrative tasks are often where children with a limited working memory capacity reach that “leading edge”.

Gillam and Johnston (1992) compared the spoken and written narrative skills of children with SLI to 3 groups of control children (age-matched, language-matched, and reading-matched). Children produced stories from sets of color pictures that were later analysed for complexity of linguistic forms and content. The children with SLI evidenced deficits relative to all control groups in both spoken and written narratives in one measure of linguistic form (number of grammatically unacceptable T-units). Further evidence that narrative production is particularly difficult for children with SLI comes from Miranda, McCabe and Bliss (1998). These researchers examined 5 aspects of narrative skills (topic maintenance, event sequencing, explicitness, conjunctive cohesion, and fluency) in children with SLI and 2 groups of control children (age-matched and language-matched). All 5 dimensions were impaired in the SLI children relative to both control groups. Botting, Faragher, Simkin, Knox and Conti-Ramsden (2001) provide support for the importance of examining narrative skills in children with SLI. They assessed a group of 117 children with SLI at age 7 and then reassessed them at age 11 to determine predictors of overall prognosis. Narrative retelling and expressive syntax were the two strongest predictors of language ability 4 years later. The current research suggests that children with SLI exhibit a deficit in narrative production relative to both age and language-matched peers, and that this deficit is important as a predictor of later prognosis.
The correlation of working memory and narrative production invites speculation as to the nature of this relationship. There are probably many points of connection, but one with particular relevance to the central executive was proposed by Naremore (1997) who argues that a successful narrative requires mapping information onto a framework stored in long-term memory. This mapping would require working memory resources to activate information from long-term storage and integrate it with current information. A child with a large working memory capacity would possess the resources to sufficiently carry out this challenging task; however, a child with a decreased working memory would necessarily experience trade-offs. Perhaps, part of the narrative framework could fail to remain activated, thus important elements of the story would be deleted. Alternatively, the framework could remain activated, but the linguistic items meant to fill in the slots could be incomplete. For example, an inability to clearly linguistically delineate characters during a narrative task could result from a combination of adequate knowledge of the framework and a lack of the working memory resources needed to accurately label each character.

The current results provide some suggestion that working memory, measured independently of language, is related to narrative production. Children with normal language development who earned high scores on the visual-spatial processing task also tended to earn high scores on the narrative task. This, of course, was not true for the children with SLI, many of whom could process impressive amounts of visual information but were very poor storytellers. How do we understand this group difference? The most straightforward explanation lies in the complexity of the narrative task. In addition to its central processing demands, any given narrative draws on a
child’s general knowledge of events, knowledge of story schemes, ability to assess the needs of the listener, conceptual development in areas such as time and causality, event knowledge, language representation – and probably more. Gaps in any one of these areas could stress the entire system. We know that children with SLI have less robust language representations, and the SLI group in this study had particular difficulties with lexical processing. Since narratives are inescapably linguistic, it is not ultimately surprising to find low narrative scores. They may be able to manipulate and coordinate visual information, but this central executive capacity cannot compensate for weaknesses elsewhere.

In summary, narrative production is a complex aspect of language that is challenging for all children, particularly those with language impairments. The current study provides evidence of a relationship between narrative production and working memory. As narrative production is an important predictor for later language development and a critical element of school success, further research exploring the nature of this relationship is needed.

4.4 **Implications for Future Research**

Similar to other research investigating language processing in a clinical population, the current study had a small sample size, so the results need replication. Two methodological issues require further comment.

4.4.1 **Difficulty of dual tasks**

Interpretation of several tasks in the current study proved difficult because many children performed at floor levels. Variance in the integrating, coordinating and visual
processing tasks was limited. In a replication of this study, it would be useful to begin at an earlier span level (i.e. only 1 or 2 objects or words to remember).

Another useful amendment to the method for the dual tasks would be to equate tasks so that single modality storage requirements are equivalently demanding for all children, as in Reggin (2002). For example, a child who achieved an auditory-verbal span of 3 would complete the dual tasks only at a span of 3, and performance would be compared to a child whose auditory-verbal span is 4 working at a span of 4 on the dual tasks. This way, differences between groups would be attributable more definitively to central executive demands, not storage differences. One challenge of this methodological change would be to determine what span to present the dual task when a child’s storage span differs between auditory-verbal and visual-spatial tasks. In the coordinating task, it is possible to present a task where the number of auditory and visual stimuli differed; however, this is impossible given the nature of the one to one correlations in the integrating task. Nevertheless, these two changes would more definitively demonstrate either impaired or unimpaired central executive processing in children with SLI.

4.4.2 Visual-spatial processing task

A further challenge to interpreting the findings from the current study lies in the inherent differences between the requirements of the visual-spatial and auditory-verbal processing tasks. Processing of the auditory-verbal material required activation of information from long-term storage (i.e. size of the referent). The visual-spatial processing task relied only on the information encoded during the grid presentation. Moreover, relative to the visual-spatial storage task, the visual-spatial processing task had
2 additional demands: 1) categorization of shapes, 2) storage of shapes. This task could actually be labelled a storage + storage + processing task. One could argue that categorization of two identical objects is not a true processing task, but requires instead extra storage demands. The difficulty of this task was evidenced by the large effects of processing in this modality. Further research to investigate visual-spatial working memory with another task would be interesting to see if visual-spatial processing is truly as difficult as the current findings indicate.

4.5 Implications for Clinical Practice

The current study has important implication for the assessment and treatment of children with language disorders. The strength of storage and processing in a visual modality can be used to support language learning. Children with SLI might benefit from the use of visual supports to assist in their language processing. For example, an SLI child in a classroom would benefit from use of pictures and diagrams when the teacher is giving instructions about how to complete a task. Two cautionary notes are warranted. Firstly, there is great variability among children. Some of the children in this study showed a very clear dissociation between auditory-verbal and visual-spatial working memory; however, not all children evidenced this pattern. Exploration of visual-spatial memory is an important part of the assessment process to determine if a child with SLI does indeed possess strong visual-spatial storage and processing skills. Secondly, it is important to consider the system as a whole. Results from the integrating task provide some evidence that children with SLI might experiences difficulties in combining
information from two modalities. It is important that adding visual supports does not overwhelm a larger limited capacity system.

Another important implication for the assessment process is to consider the demands of both storage and processing. The task that required auditory-verbal processing in addition to storage exposed group differences more than the task that required storage only. Make certain that assessment tasks are representative of the complex storage and processing requirements of language. A commonly used assessment tool, the Peabody Picture Vocabulary Test (Dunn & Dunn, 1997) does not require such complexity. An assessment based solely on such measures may fail to identify a language-impaired child.

One final implication for clinical practice is derived from the finding that working memory impacts narrative ability. For a child who is struggling with narrative production, providing memory support might improve performance. For example, provide the child with sequential pictures that structure the story, or discuss and write down names for the characters in advance. Such supports would decrease the memory load, thereby leaving the child with more resources available to plan and formulate an interesting, coherent narrative.

4.6 Conclusions

The current study investigated the role of the central executive in combining information from different domains and balancing processing and storage demands in children with SLI. The data suggests at least preliminary answers to all the research questions. In the first set of tasks, children with SLI were able to store less auditory-
verbal information and showed a greater decrement in performance when processing demands increased relative to their peers. In contrast, no deficits in visual-spatial storage or processing were found. However, considering the larger literature on visual processing, it may be premature to conclude that the difficulties of children with SLI are limited to the auditory-verbal domain. Instead, further explorations of memory strategies and temporal processing as they related to the visual-spatial domain are warranted. The second set of tasks investigated group differences in the central executive requirements necessary to integrate and coordinate information from different domains. A group difference emerged on the integration task, such that children with SLI performed more poorly than their peers. Variation in the use of memory strategy and temporal processing might explain this finding. Coordination was equally difficult for all children. The final research question investigated how working memory correlates to narrative production; a significant relationship exists between the tasks when working memory is measured in the auditory-verbal domain, using a task that requires both processing and storage. The contribution of visual-spatial working memory to language processing requires further investigation. One theme that emerged from all experimental tasks is the importance of using complex measures of working memory that require both processing and storage to explore group differences in working memory capacity and connections to language.

This study provided insight into the storage and processing abilities of children with SLI in both auditory-verbal and visual-spatial domains; however it also raised many questions important to our understanding of both working memory and SLI, thus inviting future research.
5 References


Gillam, R.B. (in press). *Test of Narrative Language.* Austin, TX: Pro-Ed


Appendices

Appendix A: Lexical properties of stimulus words

<table>
<thead>
<tr>
<th>Group</th>
<th>Word</th>
<th>Semantic Category</th>
<th>AoA(^5) (months)</th>
<th>Imageability(^6) (Scale 1-7)</th>
<th>Name(^7) Agreement (%)</th>
<th>Frequency(^8) (Scale 1-5)</th>
<th>Familiarity(^9) (Scale 1-5)</th>
<th>Neighborhood Density(^10)</th>
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5 From MacArthur Communicative Development Inventory website (http://www.sci.sdsu.edu/cdi/). Age at which 75% of children are reported to produce the word.
6 From Morrison et al. (1997). 7 point rating scale, 1=very hard to conjure up a mental image, 7=very easy to conjure up a mental image. M=6.15, SD=.39.
7 From Morrison et al. (1997). Percentage of participants who provided the target name.
8 From Morrison et al. (1997). Frequency with which participants encountered words, either spoken or written. 5 point rating scale, 1 = less than once a year to 5 = at least once a day, M=2.73, SD=.86.
9 From Morrison et al. (1997). 5 point rating scale of the “degree to which you think about or come into contact with a concept”. 1=very unfamiliar, 5=very familiar.
Appendix B: Sample pictures for the pre-test of words and categorization skill.

Snodgrass Vanderwart like pictures developed by Rossion and Portois (2001)

Microsoft Clipart pictures

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10 From Mitchell Sommer’s website (http://128.252.27.56/Neighborhood/NeighborHome.asp). Neighborhood Density could only be calculated for words containing more than 2 phonemes. ‘fridge’ was not in the lexicon, therefore neighborhood density for this item could not be calculated.
Appendix C: Sample objects for visual-spatial working memory tasks.