Examining the Extent to Which General Cognitive Deficits Can Explain the Grammatical Profile in Specific Language Impairment: A Simulation Paradigm

Hannah Louise Witherstone

PhD

University of York

Psychology

April 2016

Abstract

This thesis set out to examine whether deficits in general cognitive processes could explain the hierarchy of inflectional difficulty seen in Specific Language Impairment. A simulation approach was largely adopted, in which the online inflectional processing skills of typically-developing children were assessed when sentences were processed under conditions of cognitive stress.

Experiment 1 investigated the speed of processing account, which argues that children with SLI experience ‘generalised slowing’. Typically-developing children demonstrated an SLI-like pattern of inflectional difficulty when sentences were compressed by 30%, and this was replicated in Experiment 2. Experiment 2 also increased cognitive load by introducing noise masks and by lengthening sentences, to test the auditory perception and phonological working memory deficit accounts of SLI, respectively. No other stressors resulted in an SLI-like pattern of inflectional difficulty in the typically-developing participants. Experiment 3 re-examined the effect of noise masks as a cognitive stressor and manipulated the signal-to-noise ratio, but still no SLI-like inflectional impairment was simulated. Collectively, the findings from Experiments One, Two and Three suggest that a speed of processing deficit may be central to the inflectional difficulties seen in SLI.

This idea was further examined in Experiment 4, where the simulation paradigm was ‘flipped’: Children with SLI completed an online measure of inflectional awareness when sentences were slowed down, effectively lightening the cognitive load. The children’s morphological performance improved as a result of slowing the sentences down, however deficits in the regular past tense remained.

The results of the experiments contained within this thesis strongly support the notion that children with SLI experience ‘generalised slowing’, and that this plays a central role in the morphology deficits that are so prevalent in the disorder. The results also support the Surface Hypothesis of SLI, which argues that the inflectional deficits are the consequence of an interplay between speed of processing and the phonological properties of inflections. This thesis did not provide support for the auditory processing or phonological working memory deficit accounts of SLI, although it is possible that these impairments are present in children with SLI, but that they do not play a causal role in the difficulties with inflectional morphology.

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Acknowledgements

Firstly, I would like to express my sincere gratitude to all those involved in supervising and guiding this research. To my supervisor, Emma Hayiou-Thomas, for her ever-strong guidance, belief and support, and for helping me to develop as an independent researcher. To Graham Hitch, who supervised me for the first year of my PhD whilst Emma was on Maternity Leave and who has been a constant source of advice and clarity. To the members of my research committee: Gareth Gaskell and Sven Mattys, for their insightful comments and valuable contributions to knowledge and experimental design.

Thanks also go to the hundreds of children who participated in the experiments of this thesis. Without them, this research would not have been possible. My thanks extend to the many parents, schools and teachers who allowed me to collect data, and who made the process an enjoyable one.

I would next like to express my deepest appreciation to my family and friends, who have only ever wanted me to be happy, and to do what I love. To my Mum, for always thinking that I am a Superstar, and for being a listening ear throughout the years of rollercoaster emotions. For being a true inspiration, and for continuing to fight, even when your whole world was ripped at the seams. To my Dad, for always telling me "well done That Girl", and to my late step-father for knowing that I could do it; I'm so saddened that you couldn't be here to see it.

My most heartfelt thanks go to my husband. Tom, you have been the most unfailingly-supportive rock throughout these turbulent years. You have always believed in me, and have always pushed me to achieve my dreams. If it wasn't for you, I would most certainly not be in this position right now – writing the very last passage of text for my PhD thesis. You left your entire world behind to move with me to York so that I could pursue my dreams whilst yours were put on hold. You have never let me forget the importance of love and laughter, even during the darkest of times. For that I am eternally grateful.

This PhD has seen the most wonderful, and the most heart-breaking moments of my life. I married my very best friend, and have been so fortunate to have had two amazing children during my studies – Lewis (Wild Boy) and Alice (Tornado Girl) – who make my heart explode every day. Lewis was born two months premature and although it was a rough first few months, he is (miraculously) perfectly healthy. The last year of this PhD in particular has been, quite simply, dreadful. Unbearable at times. My step-father was unexpectedly diagnosed with terminal cancer in June 2015 and passed away just 10 days later. One week after the funeral my then-14-month-old baby girl was hospitalised with a meningitis-like virus. A week of tubes, machines, needles and drugs thankfully resulted in a full recovery. A few weeks later, we had to say goodbye to the most wonderful Canine Companion: Roo our black Labrador. I want to thank Roo for being a constant source of love and affection throughout the years. For always greeting us at the door with a wagging tail, for being so accepting and gentle with Wild Boy and Tornado Girl, for loving life, for running fast and swimming hard, and for always squeezing in between us on the bed at the end of the day.

At times, this PhD has seemed insurmountable. I cannot quite believe that I am almost at the end. It’s been one heck of a ride.

Author's Declaration

I declare that the work presented within this thesis is my own work and has not been previously submitted for any other degree or qualification. All sources are acknowledged as references.

This research was supported by a studentship from the Economic and Social Research Council (ESRC) awarded to the candidate.

Selected aspects of the research have been presented elsewhere:

Witherstone, H.L., & Hayiou-Thomas, M.E. (2011). Speeding Sentence Presentation Rate: The Effects on Inflectional Morphology. *Poster presented at the Child Language Seminars, Newcastle, July 2011.*

Witherstone, H.L. (2013). Children with Specific Language Impairment. *Invited talk given at York St. John's University, February 2013*

Witherstone, H.L. & Hayiou-Thomas, M.E. (2013). Simulating the Inflectional Morphology Deficits of Specific Language Impairment. *Paper presented at the Child Language Seminars, Manchester, July 2013.*

Witherstone, H.L. (2013). Non-linguistic deficits in Specific Language Impairment. *Invited talk given at Nottingham Trent University, September 2013*

Chapter 1. Literature Review

Approximately 7% of young children demonstrate impairments with language learning despite otherwise normal development (Tomblin et al., 1997). These children are identified as having Specific Language Impairment (SLI), and they experience deficits in a wide variety of language domains including vocabulary acquisition and grammatical development. The repercussions of having SLI are extensive, and range beyond the verbal domain: Children with a diagnosis of SLI in the preschool years have an increased risk of experiencing literacy difficulties in the school years (e.g. Stothard, Snowling, Bishop, Chipchase & Kaplan, 1998), as well as writing difficulties (e.g. Mackie & Dockrell, 2004) and psychosocial problems (e.g. Snowling, Bishop, Stothard, Chipchase & Kaplan, 2006). The underlying cause of SLI is not well understood, and it is a much-debated topic.

This thesis is concerned with the inflectional impairments in Specific Language Impairment, and the extent to which deficits in general cognitive processes can account for these. This chapter will explore the development of grammar in typically-developing English-speaking children, with a particular focus on the typical development of inflectional morphology. This chapter will then move on to discuss Specific Language Impairment, briefly covering the diagnosis, persistence and heterogeneity of the disorder before moving on to exploring the nature and potential cognitive causes of the inflectional morphology deficits that are so persistent. The chapter will then move on to explore cognitive load as an experimental paradigm, and the simulation of SLI in typically-developing children. A framework for the experiments contained within this thesis will be outlined, which looks to empirically test the leading cognitive theories of the inflectional difficulties seen in Specific Language Impairment by adopting a simulation paradigm.

1.1. Typical Development of Grammar

Although the focus of this thesis is the reasons behind the potential causes of inflectional difficulty in Specific Language Impairment (SLI), it is important to begin by understanding the foundations of language and grammar. Once we understand how language and grammar develop typically, we can begin to consider how and why this might go wrong for some children.

Note that unless otherwise stated, the information in this thesis concerns English-speaking children.

Once a child has learnt a new word (both how to pronounce it and what it means), they must abide by the grammatical rules of their native language in order to use that word correctly in their utterances. Broadly speaking, the domain of grammar can be separated into syntax and morphology.

Syntax refers to the rules that govern how words can be combined to form legitimate sentences. For instance, in English the typical order of words within a sentence is ‘subject-verb-object’, with other configurations often being syntactically incorrect e.g. “the dog (s) chased (v) the ball (o)” is syntactically valid, whereas “chased (v) the dog (s) the ball (o)” is not.

Morphology refers to the underlying structure of words, and the decomposition into elements of minimum meaning (Bishop & Mogford, 1993). Inflectional morphology is the process of adding a morpheme (or inflection) to a word in order to denote tense, agreement or number. For example, the ‘regular past tense’ inflection (*–ed*) is added to the end of regular verbs to place them in the past tense (walk > walk*ed*). In the same vein, the ‘regular plural’ inflection (-*s*) is added to the end of regular nouns to denote plurality (one cat > two cat*s*). The English language contains numerous inflections, some of which are regular (kick > kick*ed*) and some of which are irregular (catch > *caught*). Table 1 details some of the inflections found in the English language.

Table 1

Examples of inflections found in the English language

Word Class	Morpheme	Grammatical Function	Component	Example
Noun	Regular Plural	Marks number; more than one	-s	There are two dog**s** in the park
	Regular Possessive	Marks ownership	-s	The gentleman'**s** suitcase was left on the train
Verb	Regular Past Tense	Marks for past action	-ed	Yesterday, the boy kick**ed** the ball
	Regular Third Person Singular	Marks for action carried out by a third person	-s	Every day, the girl walk**s** to the shop
	Regular Present Participle	Marks action carried out in the present tense	-ing	The cat is chas**ing** a mouse
Adjective	Comparative	Marks for comparison	-er	The water was cold**er** than last week

Bishop and Mogford (1993) highlighted that before the 1970s, there was very little understanding about how children learn grammar, and how they move from errorful child use to accurate adult-like levels. In his influential work, Brown (1973) noted that children appear to follow the grammatical rules of their native language right from the start. Brown showed that even when combining just two simple words, children follow grammatical constraints, such as those pertaining to word order. For instance, a child will rarely say "*juice more*" as opposed to *"more juice"*.

As a child's language develops, their use of grammar becomes increasingly more complex. Children slowly use more inflectional morphology, and begin to use more complex sentence constructions. For example, the use of one-word subject sentences moves to two-word subject+object sentences and the use of subordinate clauses begins, and so on. Bishop and Mogford (1993) continue to highlight that the frequent overgeneralisation errors (e.g. *he runned)* made by children indicate that they may be learning grammatical rules, rather than simply replicating what they hear around them.

1.1.1. Typical development of inflectional morphology. Typically-developing children begin to make use of inflectional morphology early in their language development, and demonstrate that they possess implicit knowledge of linguistic morphology from as young as 4-years-old (cf. Berko, 1958). In a highly-influential paper, Berko (1958) asked preschool children to inflect nonsense words in order to gauge their acquisition of morphological rules. The children were shown pictures of a make-believe character or activity, which was labelled with a nonsense name, and were required to complete a sentence about it. For instance, the child was shown a drawing of a bird-like creature and was told:

> *"This is a WUG. Now there is another one. There are two of them. There are two ____________"*

Almost all children completed the above sentence with the word /wugs/, thus making use of the regular plural -*s* inflection with a word they had never encountered. Berko demonstrated the same regularisation effect for constructions prompting a wide variety of English morphemes, including the regular past tense -*ed*, the third person singular -*s* and the present progressive -*ing*. Berko's findings demonstrate that even very young children have a concept of the regular inflectional rules of their native language, and that they are able to generalise these rules to new, novel words.

For English-speaking children, the development of inflectional morphology across childhood is generally characterised by a U-shaped pattern of development (Le Gard, 2004), and this is especially so for the past tense. When children begin using the past tense of verbs, they first master the highly-frequent irregular verbs and some high-frequency regular verbs. As more verbs are learnt, and vocabularies increase, children begin to make overgeneralisation errors. Over time, these overgeneralisation errors become less frequent, and children begin to demonstrate adult-like levels of inflectional morphology.

Studies that focus on the order of acquisition of morphemes allow us to understand the typical pathway of inflectional development, and can therefore allow us to identify those children who are not developing in the ‘usual’ manner (Bavin, 2009). Children begin to use basic morphological items between 19-28 months (see figure 1), and by the age of five, most typically-developing children are able to use most of the major English inflectional items.

Brown (1973) conducted an influential longitudinal study of inflectional morphology development in three typically-developing children from America. Initially, at around 12-26 months of age, the children combined individual words with little use or understanding of the grammatical constraints of the English language, although they did usually follow word-order conventions. Brown labelled this as Stage 1. Stage 2 saw the first emergence of inflectional morphology, with later stages characterised by more complex grammatical use. At the start of stage 2, Brown argued that the typically-developing children began to make sense of various formal variables, such as salience (e.g. amplitude, duration, stress, position within the sentence etc) and grammatical complexity (e.g. class membership of the bare stem and phonological properties of the stem). Semantics also need to be coded, according to Brown, before a child can fully acquire inflectional morphology. These factors include relations such as possession, number, gender and tense. Brown's results revealed a consistent order of morpheme acquisition between the three participants, in which acquisition was defined as a criterion of 90% correct use in obligatory constructions. Figure 1 details the order of acquisition of 14 grammatical morphemes. Brown's findings indicate that the move from a child's first use of a particular morpheme to their full acquisition (i.e. use in at least 90% of obligatory situations) is a gradual process, which can take as long as a year.

The order of acquisition detailed by Brown (1973, as outlined in figure 1) was largely replicated by de Villiers and de Villiers (1973). In a cross-sectional study, de Villiers and de Villiers (1973) analysed naturalised speech samples of 21 children aged 16-40 months. They found, like Brown, that the present progressive -*ing* was the first morpheme to be acquired. The plural -*s* was acquired a little later than the progressive -*ing*, and the third person singular -*s* and past tense -*ed* morphemes were acquired at approximately the same time.

Morpheme	**Example**	**Age of Mastery* (In Months)**
Present Progressive – *ing*	Mommy driv*ing*	19-28
In	Ball in cup	27-30
On	Doggie on sofa	27-33
Regular plural -*s*	Kitties eat my ice cream. Forms: /s/, /z/ and /iz/ Cats, Dogs, Classes, Wishes	27-33
Irregular past	Came, fell, broke, sat, went	25-46
Possessive 's	Mommy's balloon broke Forms: /s/, /s/ and /iz/ as in regular plural	26-40
Uncontractible copula (Verb *to be* as main verb)	He is. (Response to "Who is sick?)	28-46
Articles	I see *a* kitty.	28-46
Regular past -*ed*	Mommy pull*ed* the wagon Forms: /d/, /t/, /Id/ Pulled, Walked, Glided	26-48
Regular third person -*s*	Kathy hits Forms: /s/, /z/, and /iz/	28-50
Irregular third person	Does, has	28-50
Uncontractible auxiliary	He is. (Response to "Who is wearing your hat?")	29-48
Contractible copula	Man's big Man *is* big	29-49
Contractible auxiliary	Daddy's eating Daddy *is* eating	30-50

*Used correctly 90% of the time in obligatory contexts. Adapted from Bellugi & Brown (1964); R. Brown (1973); and J. Miller (1981).

Figure 1. morpheme age of acquisition. Table reproduced from http://www.speechtherapyct.com/whats_new/Early%20Morphological%20Development.pdf, permission granted.

The studies by Brown (1973) and de Villiers and de Villiers (1973) show that there is a relatively consistent order of morpheme acquisition in children acquiring English as their native language. This order of acquisition is seen not only in children acquiring their native language, but also by children learning English as their second language (Jia & Fuse, 2007).

What makes this consistency in findings particularly interesting is that the studies cited (Brown, 1973; Jia & Fuse, 2007; de Villiers and de Villiers, 1973) used spontaneous speech samples for their data collection, and as such the topics of conversations and the situations in which the inflections occurred were all different. As Brown argued, this suggests that "some factor or some set of factors caused these grammatical morphemes to evolve in an approximately consistent order" (Brown, 1973, p. 272). There have been numerous theories and hypotheses posed that attempt to explore these factors, which will be discussed next.

1.1.1.1 Theories of inflectional development. It has just been shown *what* children do when learning the inflectional rules of their native language, but now one must consider *how* children actually learn these rules. A highly influential theory of inflectional development is the Dual Route theory of Pinker and colleagues (e.g. Pinker & Prince, 1988). This theory proposes that initially, children store all inflected words holistically in their entire form, establishing a new 'word-specific paradigm' for each lexical item. As a child's lexicon increases, this theory suggests that they begin to implicitly detect regularities in inflectional patterns, which results in regular words becoming segmented in to stems and suffixes. This then creates 'word-general paradigms' that hold information about inflectional rules, such as adding *–ed* to regular verbs to create the past tense. Once a child has a word-general paradigm for a particular inflection, they should be able to inflect all newly-encountered words with this morphological item, regardless of surface features such as the frequency of the word, or phonological similarity to other lexical items (Marcus et al., 1992). Words that do not have regular inflections, such as irregular verbs, are handled holistically by a second system: one that is based on associative memory and the surface features of the lexical item, such as frequency and phonological structure (Oetting & Horohov, 1997).

The Dual Route theory argues that during language processing, both the rule-based and associative routes are in operation simultaneously, and are in direct competition with each other. For example, when a child must place an irregular verb in the past tense, both routes are activated. If the correct past tense form has a strong enough mental representation, that will be selected and the correct form will be produced by the child. If, however, the representation is weak, the rule-based route will dominate and an overgeneralised form will occur (e.g. he *runned*).

Although the Dual Route model is able to explain overgeneralisation errors, it cannot account for all grammatical errors in a child's language production. For example, children occasionally produce irregular inflection stems on the end of regular verbs when placing them in the past tense (Le Gard, 2004). This should not happen according to the Dual Route model, as irregular forms are supposedly stored in their entire form, as one single entry (rather that stem+suffix). In addition, experiments where children are asked to place nonwords in the past tense question the Dual Route further. The Dual Route model would predict that in these experiments all nonwords would be inflected with regular forms, given that this is the default route, and that irregular forms are simply memorisations. However, when faced with this situation, children often inflect based on the phonological properties of the nonword (Marchman, 1997). That is, they produce an irregular form if the nonword is phonologically similar to an irregular real-word and a regular form if the nonword is similar to a regular real-word.

Rumelhart and McClelland (1987) proposed an alternative hypothesis to the Dual Route model; a Single Route theory. This theory posits that all inflections are stored in one single system, with varying lexical representational strengths depending on frequency. The Single Route theory can better account for the irregular overgeneralisations and the nonword inflections that the Dual Route model struggles to do. The Single Route theory suggests that one is subject to interference effects, whereby phonologically similar words are confused. For example, the irregular verb 'go' is often incorrectly inflected as '*goed*', because (according to this model) it is phonologically similar to other regular verbs, such as mow, row and sew.

Although the Single and Dual Route models go some way in attempting to explain the development of inflectional morphology in typically-developing children, they cannot explain the specific order of morpheme acquisition detailed at the start of this section (e.g. Brown, 1973; de Villiers & de Villers, 1973). That is, they cannot explain why, for example, the regular plural -*s* is one of the first inflections to be acquired, and the third person singular -*s* is one of the later inflections to be mastered.

So what factor or set of factors might explain this hierarchy of morphological acquisition? One prominent argument in the literature is that it may be due to the token frequency of the input (Bavin, 2009). That is, the more frequently a particular morpheme is heard by a child, the easier (and earlier) it is to acquire.

Psycholinguistic literature shows that all aspects of adult language processing are sensitive to frequency effects (e.g. Bod et al., 2003; Ellis, 2002), and this is the case with children's language, too (Lieven, 2010). For instance, Lieven (2010) notes that frequency of exposure affects speed of recognition, recall accuracy, and one’s ability to encode novel, but similar, items. In one of the earliest studies investigating the link between frequency of input and lexical outcomes, Howes (1957) demonstrated that a word's strength of lexical representation was related to the frequency of its input, such that the more frequent a word was, the more visual or auditory degradation it could take without affecting recognition accuracy. Supporting this, the positive effect of increased frequency of exposure upon learning outcomes has been shown in both experimental studies (e.g. Bates & MacWhinney, 1987) and connectionist and computational simulations (e.g. Chang et al., 2006, Chater & Manning, 2006).

In addition to frequency effects impacting upon performance outcomes, studies have consistently shown age of acquisition to be negatively correlated to frequency of input (e.g. deVillers, 1985; Theakston et al., 2004). For instance, Lieven (2008) showed that frequency of input was directly related to the age of acquisition of auxiliary forms. This was supported by Wilson (2003) and Pine et al., (2008), who also found a relationship between frequency of exposure and the age at which auxiliary constructions were acquired, as well as copulas. Furthermore, Rowland and Pine (2003) demonstrated that children were able to use the correct subject-auxiliary inversion in wh- questions when forms were more frequent in input, but were less able when the forms were less frequent in input. Finally, it has consistently been shown that the level of exposure frequency affects performance on grammaticality judgement tasks, with children less successful at detecting ungrammaticality in sentences containing low-frequency items, as compared to sentences containing high-frequency items (e.g. Ambridge et al., 2008; Theakston, 2004).

Lieven (2010) supports the idea that frequency effects can impact upon general grammatical awareness by discussing the arguments contained with the Dual Route and Single Route models of English past tense learning (regular versus irregular). Here, Lieven highlights that although both models have different ideas about how past tense abilities are acquired, both have frequency as a component. That is, both argue that the more frequent an irregular form is, the less likely it is to be over-regularised (e.g. Maslen et al., 2004; Pinker & Ullman, 2003).

Although the evidence presented here seems to indicate that frequency is an important factor in determining the ease of morpheme acquisition, there are some researchers that suggest frequency is only one component of a more complex set of factors. For instance, Slobin (1985) argued that frequency alone does not fully explain how easy or difficult various aspects of language are to master. Rather, one needs to consider the form-function mappings of a linguistic item, as well as frequency. That is, Slobin argued that "language learning is helped by a one-to-one mapping between a form and its function, and this then interacts with frequency" (Slobin, 1985 p. 2548). Furthermore, Slobin suggested that there is a hierarchy of grammaticizability, based on a set of ‘accessible notions’ which influence how likely they are to be incorporated into the grammar: for example, grammatical morphemes that have clear semantic correlates (such as number) will appear in many of the world’s languages. Following on from this idea, Pinker (1984) suggested that the hierarchy of grammaticizability is also related to morphemes’ learnability, and their acquisition in childhood.

Slobin's argument was supported by Bates and MacWhinney (1989), who argued that the frequency of an item interacts with its form-function mapping consistency to determine the speed (or ease) of learning. This argument stemmed from their Competition Model (Bates & MacWhinney, 1989) which argues that, from a processing perspective, there are cues within a language which determine the ease of acquisition. It is argued that these cues are in direct competition with each other, and that the ease of acquisition of morphological items is determined by the validity of a cue (a function of its availability and reliability) in relation to the cost (cognitively-speaking) of processing it.

An alternative viewpoint relates to neighbourhood relationships. Lieven (2010) argues that tense and agreement paradigms are formed based on a network of shared phonological and semantic information. According to Lieven (2010), children initially use inflected forms which are represented as a function of input frequency, before developing morphological paradigms. Lieven argues that these are initially restricted to a small number of phonologically-similar items, but they become more abstract (i.e. applicable to more items that share fewer features) over time.

Although there is some contention in the literature surrounding the mechanics of typical inflectional morphology development, this is not the focus of this thesis. This particular piece of work is interested in exploring the inflectional difficulties experienced by children with SLI. Before the literature on SLI and inflectional morphology is discussed, it is important to understand some of the various methodologies for assessing inflectional morphology. This is so that any literature presented in later sections will be fully understood with regards to their methods and results.

1.2. Assessing Online and Offline Inflectional Morphology.

There are many ways one can assess a child's inflectional morphology skills. Broadly speaking, the methods used can be separated into 'expressive methods' and 'receptive methods'. Expressive methods involve examining a child's ability to *produce* a specific inflection, usually by listening to their naturalistic, spontaneous speech, or by eliciting the production in, for example, a sentence completion task. The work of Berko (1958) which is detailed in section 1.1.1 is one of the earliest and most influential studies to use production methods as a way of measuring inflectional morphology. Receptive methods on the other hand involve measuring a child's *awareness* of a morphological item, without requiring them to produce it. These receptive methods can either measure online or offline skills. Offline tasks are those that are thought to measure explicit inflectional awareness after sentence processing has taken place. Online measures are often regarded as more implicit in nature, and measure inflectional skills in real-time.

The most commonly-used offline measure of inflectional awareness is the grammaticality judgement task. In this task, an individual is presented with a spoken sentence that is either grammatical or ungrammatical. After they have heard the sentence, the individual is required to say whether the sentence was grammatically well-formed or not. They are not required to say *where* any grammatical mistakes were within the sentence.

When designing a grammaticality judgement task, it is important to take into account the age of the intended participants. For instance, preschool children often struggle with the demands of the grammaticality judgement task, often making judgements based on semantic, rather than grammatical, information (de Villiers & de Villiers, 1973). School-aged children do begin to make use of grammatical information during grammaticality judgement tasks, however performance varies greatly depending on the semantic complexity of the stimuli (Kail, 2004). When semantic complexity is controlled, children from the age of six can perform well on a grammaticality judgement task that assesses awareness of a variety of inflections, including (but not limited to) the regular past tense, third person singular, regular plural and the present progressive (McDonald, 2008).

The grammaticality judgement task is a binary measure, in that children either rate the sentence as grammatical or not. This has the advantage of being suitable for very young children, given the simplicity of the task (e.g.Rice, Wexler & Redmond (1999) showed it to be effective for children as young as 4;1years). In addition, the task is free of problems surrounding production and pronunciation in the participants. However, the task draws heavily on both working memory and metalinguistic skills, which may confound the results. In addition, one is not able to compare the *relative* ungrammaticality of two ungrammatical constructions (Ambridge & Lieven, 2011), or assess the reason for the judgement. For example, take the following two sentences (grammatical version: *"The man kicked two balls in the park"*):

Sentence A: "The man kicked two ball in the park"

Sentence B: "The man kick ball in the park"

Sentence A is just missing the plural inflection on the noun 'ball', whereas sentence B is missing the past tense inflection on the verb 'kick', the number 'two' and the plural on 'ball'. Both are ungrammatical, but with varying degrees. With a grammaticality judgement task however, both sentences would be regarded as equally-ungrammatical for analysis purposes. Finally, the grammaticality judgement task lacks ecological validity. Language is a rapidly-evolving medium that requires real-time processing. It is rare for real-word language to be processed in an off-line manner, such as in the grammaticality judgement task.

As an alternative to the offline grammaticality judgement task, one may use an online word monitoring task (Marslen-Wilson & Tyler, 1980). In this task, a participant is presented with a spoken sentence and is required to press a response button as soon as they hear a given target word embedded within the passage. The word monitoring task can be used to assess real-time inflectional processing (e.g. Tyler & Cobb, 1987), as well as general speed of language processing (Montgomery, 2002). In the case of measuring inflectional awareness, sentences are manipulated for grammaticality, such that the target word is immediately preceded by a word that is either appropriately inflected or inappropriately uninflected (i.e. a bare stem where there should be an inflected form). A typical pattern of results shows slower reaction times to the target word in the ungrammatical condition, as compared to the grammatical (e.g. Montgomery & Leonard, 1998). For instance, reaction times to the target 'football' are typically faster in the sentence "*last week the boy played football with his friends",* as compared to the sentence "*last week the boy play football with his friends".* This difference in reaction times indicates processing of the inflections; if there is no reaction time difference between grammatical and ungrammatical sentences, a lack of inflectional processing is implied (Montgomery & Leonard, 2006). Experimental work has shown that the word monitoring task is effective in measuring general lexical processing (Montgomery, Scudder, & Moore, 2008; Montgomery, 2002) and in assessing morpheme awareness in both children with SLI and those that are typically-developing (Montgomery & Leonard, 2006).

The word monitoring task does not require any explicit judgement from the participant as to the grammaticality of the sentence they have just heard, and as such is considered to be an implicit measure. It therefore places less demand on working memory and metalinguistic skills, as compared to grammaticality judgement tasks (Miller, Leonard, & Finneran, 2008). The word monitoring task also allows more sensitive investigation into the unconscious representations and processes involved in sentence processing (Tyler, 1992); something that more traditional off-line tasks struggle to do. Unlike the grammaticality judgement task, one can gauge some idea as to relative ungrammaticality with the word monitoring task, by comparing reaction times across sentences with varying degrees of ungrammaticality. The word monitoring task is also more ecologically-valid than the grammaticality judgement task, as it requires real-time language processing, just as the real-world does. However, the word monitoring task does require a speeded response and a good level of attention in order to perform well. As such, it is possible that children may have to be older in studies using this methodology, and there is more room for error or floor effects.

1.3. Specific Language Impairment

So far, this thesis has explored how language and grammar develop typically, with a particular focus on the development of inflectional morphology. The assessment of inflectional morphology in children was then covered to ease comprehension in the following sections. Although for the most part children acquire their native language and grammatical rules relatively easily, some individuals develop atypical language profiles that are identifiable as language disorders. The language disorder that is the focus of this thesis is Specific Language Impairment (SLI).

In an influential epidemiological study of US kindergarten children, Tomblin et al. (1997) identified that approximately 7% of English-speaking children had a diagnosis of SLI, with a ratio of 1.33:1 boys to girls. Children with SLI experience a wide range of language problems including (but not limited to) argument structure, the use of wh-questions, inflectional morphology, prepositions, determiners, and the use of embedded sentences (Clahsen & Almazan, 1998; Leonard, 2014; van der Lely

& Battell, 2003; van der Lely, 1998). SLI affects not only a child's language, but also their psychosocial development (Snowling, Bishop, Stothard, Chipchase, & Kaplan, 2006), general psychiatric health (Beitchman, Cohen, Konstantareas, & Tannock, 1996), and their later literacy aptitude (Bishop & Adams, 1990; Botting, Faragher, Simkin, Knox, & Conti-Ramsden, 2001; Mcarthur, Hogben, Edwards, Heath, & Mengler, 2013). These difficulties affect a child right through their school life and into adulthood (Conti-Ramsden, Knox, Botting, & Simkin, 2002; Miller et al., 2008).

1.3.1. Diagnosis of SLI. SLI is a particularly intriguing disorder as the language difficulties experienced cannot be accounted for by impairments in hearing or speech, neurological deficits, developmental disorder, or general linguistic delay (Leonard, 2014). Currently, a clinical diagnosis of SLI relies on discrepancy; that is, children must demonstrate below-average language (usually a standard score of under 85) whilst having nonverbal skills within the normal range (usually a standard score of 85 and above), as measured by standardised tests (Bishop, 2004; Leonard, 2014). Children who have both language and IQ standard scores that fall below normal parameters are categorised as those with 'non-specific language impairment' (NLI), and as such are often regarded as a separate clinical group to children with SLI.

It is important to note that there are several concerns among academics and healthcare professionals with regards to the diagnosis of SLI. Firstly, Bishop (1994) argues that the reliability is often poor for verbal-nonverbal discrepancy magnitude and that children with SLI (as diagnosed by the current clinical guidelines) should not be regarded as different to children with NLI. Specifically, literature has demonstrated that children with SLI show the same specific pattern of language difficulties as children with below-average standard scores on language and IQ measures (Rice, Tomblin, Richman, & Marquis, 2004). In addition, children with SLI and NLI respond to treatment in the same manner (Fey, Long, & Cleave, 1994). Lastly, Tager-Flusberg and Cooper (1999) argued that, based on the evidence available at the time of their publication, there was no evidence to suggest that children with SLI and NLI were two distinct groups.

In addition to issues with using a discrepancy definition, there are concerns surrounding differing diagnostic tests between studies. As previously described, children with SLI are currently diagnosed using a discrepancy between verbal and nonverbal scores on standardised tests. However, there is no universal test battery, and there are no established guidelines as to what particular linguistic domains should be examined when identifying children with SLI (Tomblin, Records & Zhang, 1996). The choice of standardised tests used (mainly the language measures, but there is also variability in the nonverbal measures) when identifying whether a child has SLI or not varies considerably, which can result in children receiving different diagnoses depending on the tests used. To highlight this point, Silveira (2011) identifies one child in her sample who was assessed for SLI using two different non-verbal tests. The child in question achieved an age-appropriate score on one of the tests (Raven's Matrices), but scored below-average (standard score of 80) on the other test (Weschler Intelligence Scale for Children). If the former test was used in a study's test battery, this particular child would be identified as having SLI. However, if the latter test was used, the child would be classified as having NLI.

Following on from this, there does not appear to be agreement about the cut-off point for standardised tests, which places a child in the SLI or typically-developing category. Whilst most researchers use 85 standard score points as the cut-off, some use a score of 80 (Aram, Morris & Hall, 1993). This point brings in to question the comparison of SLI groups across studies; those that differ in diagnostic tests used may also, as a result, differ in their populations. That is, children may be classified as having SLI in one study, but as typically-developing in another study that has a different test battery or cut-off point.

In addition to problems with varying test batteries and cut-off points, it has been argued that nonverbal standardised tests used in the assessment of SLI may tap areas of difficulty for these children, rather than measuring an apparently-unimpaired domain (Johnston, 1994). Indeed, Leonard (2014) covers an extensive range of literature that suggests children with SLI have difficulties in areas that are not related to language cognition. Some researchers have highlighted that, although SLI samples fall within 'normal' non-verbal limits, they actually sit at the lower end of the 'normal' scale. For example, Webster et al. (2006) compared the nonverbal skills of children with SLI and typically-developing children of the same age. Despite both groups' nonverbal IQ scores falling within the normal range, the mean score from the SLI group was at the lower end of 'normal'. Catts et al. (2002) supported this finding, showing their sample of children with SLI to have nonverbal IQs at the lower end of the normal range.

Evans (2001) extends on this point, and highlights the wide-ranging difficulties that children with SLI experience, even outside of the linguistic domain. Specifically, she argues that children with SLI demonstrate "... deficits in vocabulary and word-finding ... morphology, syntax, pragmatics, nonverbal and verbal working memory, slower verbal and nonverbal processing, and deficits in speech perception" (p.40). This quote, combined with the research demonstrating wider non-linguistic deficits in SLI, really demonstrates that it may not be a linguistic-specific disorder, and that we need to consider impairments outside of the linguistic domain when looking at the aetiology of SLI. This idea shapes the core foundations of this thesis.

1.3.2. Persistence of SLI. It has been reported that many children with SLI may resolve their language difficulties as they get older (Bishop & Edmundson, 1987; Tomblin et al., 1997). Bishop and Edmundson (1987) conducted an 18-month longitudinal study on 87 4-year old children with language difficulties. Forty four percent of children who were classified as having SLI at 4-years of age appeared to have resolved their language difficulties 18 months later. This is compared to just 11% of children who at 4-years presented language difficulties alongside poor nonverbal IQ scores (2SD below the mean – 'general delay' group). Bishop and Adams (1990) followed the same group of children up when they were 8.5years, and found that those children who had 'resolved' language difficulties at 5.5years were performing age-appropriately on measures of language, reading and spelling, but did have mild deficits in receptive grammatical skills. The children whose language difficulties persisted at 5.5years continued to show quite significant difficulties with all areas of language and reading at this 8.5year follow-up. Interestingly, when Stothard, Snowling, Chipchase, and Kaplan (1998) followed 71 of the children up at 15-16years of age, nearly *all* children (even those with 'resolved' language at 5.5years and thus good outcomes at 8.5years) were showing impairments in phonological skills, literacy ability, and GCSE performance. As expected, it was the children with poor nonverbal IQ at the outset of the study who had the poorest outcomes at this adolescent time point.

This collection of studies demonstrates that the long-term language and reading outcomes for children with preschool language impairment are dependent upon the severity of the difficulties at the start of school. Children whose language difficulties are resolved by the start of school do seem to make good language and literacy progress, but there is some evidence for slight impairments come adolescence. Children whose language difficulties persisted into the start of school showed ongoing difficulties; this is especially so for children whose language impairment was accompanied by poor nonverbal IQ.

The persistence of SLI and the negative impact it has upon the wider aspects of development highlights the importance of research in this field. It is crucial that this disorder is fully understood, so that effective interventions and provision strategies can be put in place in order to support these children to reach their maximum social, educational and psychosocial potential.

1.3.3. Inflectional morphology in SLI. It is generally agreed that grammar is the most impaired area of language acquisition in children with SLI (see Leonard, 2014 for an extensive review). Within the domain of grammar, inflectional morphology appears to be an area of particular difficulty for children with SLI, as compared to both age- and language-matched controls (Oetting & Horohov, 1997; Rice & Wexler, 1996). This is the case for children with SLI, even when their more general grammatical and lexical difficulties are taken into account (Bishop, 1997).

Although greatly impaired, children with SLI do not seem to show a blanket deficit with inflectional morphology; rather they experience a gradient of difficulty such that some inflections are more troublesome to master than others (Leonard, 2014). It is well established in the literature that tense and agreement morphemes appear to pose particular difficulty for children with SLI (Conti-Ramsden & Jones, 1997; Leonard, Deevy, Wong, Stokes, & Fletcher, 2007; Leonard, Eyer, Bedore, & Grela, 1997; Oetting & Horohov, 1997; Rice, Wexler, & Cleave, 1995), and that these deficits extend well into the school years (Marchman, Wulfeck, & Ellis Weismer, 1999; Norbury, Bishop, & Briscoe, 2001; Rice, Wexler, & Hershberger, 1998; Rice et al., 2004). Deficits in morphemes not pertaining to tense or agreement have also been documented, such as the possessive –s (Leonard, 1995) and plural –s (Eyer & Leonard, 1995; Leonard, McGregor & Allen, 1992) inflections. However, deficits in these non-tense/agreement morphemes are reported less in the literature, and are often resolved early in a child with SLI (Leonard, Camarata, Pawlowska, Brown, & Camarata, 2008) as compared to tense and agreement inflections. As such, deficits in non-tense/agreement morphemes may be milder than those that are tied to tense and/or agreement.

Research consistently shows the regular past tense –ed inflection (*I walk > I walk**ed**)* to be the most impaired morphological item for English-speaking children with SLI (Leonard et al., 1992; Rice et al., 1995; Rice & Wexler, 1996). For instance, Rice et al. (1995) investigated the use of regular past tense morphology in the spontaneous speech of 5-year-old children with SLI. It was found they used the regular past tense in an average of just 18% of obligatory situations, as compared to 56% in a language-matched group and 90% in an age-matched condition. Further analyses of natural speech samples of children with SLI confirm that the regular past tense is used less frequently than typically-developing age- and language-matched controls (e.g. Leonard, Davis, & Deevy, 2007; Rice & Wexler, 1996).

In addition to spontaneous speech studies, experimental work has also shown children with SLI to be most impaired in the regular past tense inflection (e.g. Oetting & Horohov, 1997; Van Der Lely & Ullman, 2001), as compared to other verb inflections. In support of these findings, a discriminant analysis comparing potential clinical markers of SLI found regular past tense abilities to be the best marker (as measured by an expressive elicitation/sentence-completion task), along with nonword repetition which will be discussed later in this chapter (Conti-Ramsden, 2003).

Rice, Wexler, Marquis and Hershberger (2000) were one of the first research groups to directly compare regular and irregular past tense abilities in the same sample of children with SLI, using a longitudinal design. In this study, children with SLI (mean age at the outset of the study 4;8 years) were compared to two control groups: one matched on chronological age (mean age at study outset 4;11) and one matched on language ability (as measured by mean length of utterance, mean age at study outset 3;0). Pictures were used to elicit the past tense forms of verbs, and children were tested twice a year for seven testing occasions. For the regular past tense constructions, children with SLI performed more poorly than the chronological age matches throughout the study. Children with SLI performed more poorly than the language-matched group only in testing periods 3-7 (i.e. between the ages of 6 and 8.5 years); equal performance was seen for the regular past tense when the children with SLI were tested between the ages of 4 and 6 years. For the irregular past tense constructions, the children with SLI performed as well as their language-matched counterparts at all test points. Both groups performed consistently more poorly than the chronological-age matches. All three groups made more errors for the irregular past tense, as compared to the regular past tense.

As Rice et al. (2000) was longitudinal in design, the authors were able to evaluate growth curves of grammatical ability in their sample. For all groups, growth in irregular past tense abilities increased steadily over time (i.e. in a linear fashion), whereas regular past tense skills showed nonlinear elements where there were periods of fast change, followed by plateaus. Importantly, the children with SLI showed similar growth patterns to both control groups for both past tense constructions, indicating their development may be delayed, rather than deviant.

Rice et al. (2000) clearly demonstrates the disproportionate difficulty children with SLI have with past tense marking. This is especially the case for marking of the regular past tense, where performance is significantly below that expected given their weaker language skills (from the age of 6 at least). Combined with the large amount of research presented thus far on regular past tense deficits (Conti-Ramsden, 2003; Leonard et al., 1992; Leonard, Davis, et al., 2007; Oetting & Horohov, 1997; Rice et al., 1995; Rice & Wexler, 1996; Van Der Lely & Ullman, 2001), it is clear that the regular past tense poses a great deal of difficulty for children with SLI.

Although to a lesser extent than the regular past tense, errors in the third person singular –s inflection (*I walk*, *she walk**s***) are also common in children with SLI (Bishop, 1994; Leonard et al., 1992; Rice & Wexler, 1996). Rice et al.'s (1995) study of spontaneous speech samples noted that children with SLI used the third-person singular –*s* inflection in just 30% of obligatory situations, as compared to 45% in the language-matched group and 90% in the aged-matched children. A comparison of the figures derived from Rice et al. (1995) indicates that whilst the third-person singular is impaired in SLI, it is to a lesser extent than the regular past tense inflection.

The ability of children with SLI to use the regular plural –*s* inflection (*one cat, two cats*) seems to remain relatively unimpaired (e.g. Bishop, 1994). However, it must be noted that there are some studies suggesting a mild, but significant deficit in this inflection for children with SLI. For example, Oetting & Rice (1993) found that five-year-old children with SLI used the regular plural –*s* in 83% of obligatory situations, as compared to 93% in a language-matched control group. However, the sample in Oetting and Rice (1993) was hugely varied with regards to regular plural deficits, and there was a large proportion of the sample that showed no deficit. It may be that only those children who are most severely-affected by SLI experience deficits in the regular plural, as well as the verb deficits explored earlier. Alternatively, it could be that children with SLI quickly 'grow-out' of plural deficits, and that only the younger ones demonstrate an impairment, relative to controls: The children in Oetting and Rice (1993) were very young, mostly having just turned five-years-old. In contrast the children in Bishop's (1994) study ranged in age from 8-12 years.

In sum, it appears that the regular past tense poses enormous difficulty for children with SLI, even when their general language delay is taken into account. The third person singular inflection is moderately difficult, and the regular plural is relatively unimpaired (or impaired to a small degree) in children with SLI. To highlight this pattern further, the following graph (figure 2) represents data taken from Rice and Wexler's (1996) study on the inflectional morphology used in the spontaneous speech of children with SLI and controls.

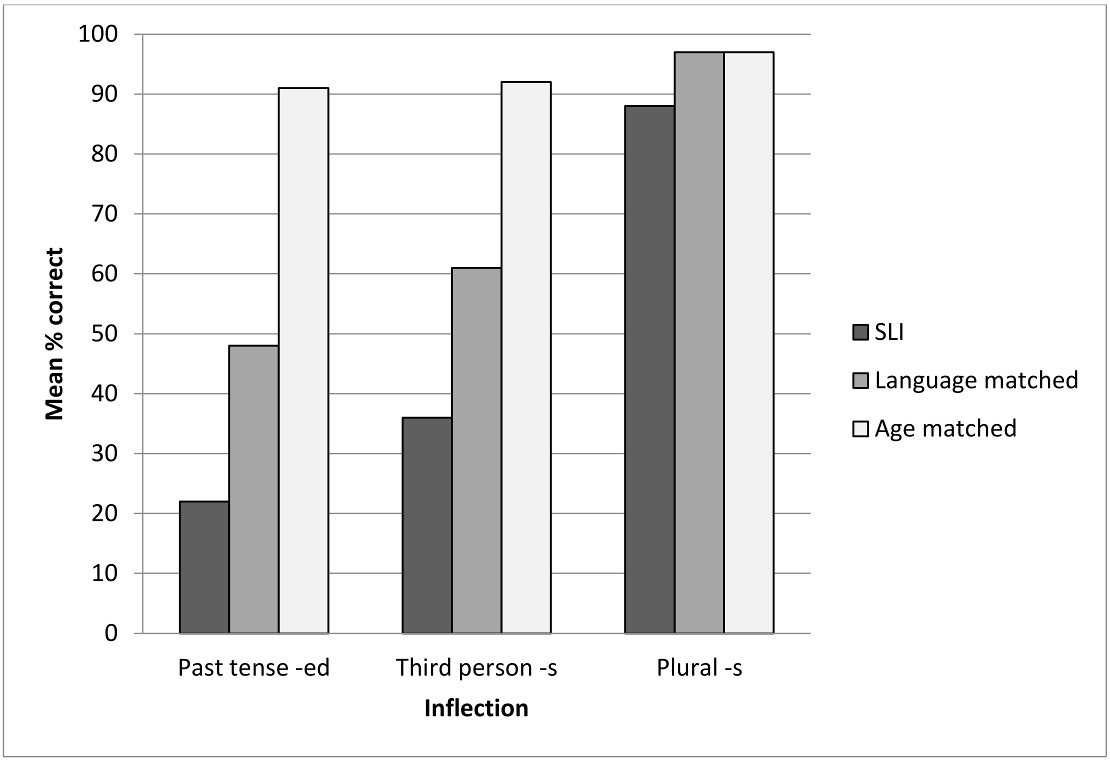


Figure 2: percentage of inflections correctly used in obligatory situations in the spontaneous speech of preschool children with SLI, language-matched and age-matched controls. Data re-graphed from Rice and Wexler (1996), permission granted.

Despite children with SLI experiencing difficulty with many inflections, there are some instances where inflectional morphology is unimpaired. For example, it is well-established that the progressive /–ing/ is unaffected in children with SLI (e.g. Roberts, Rescorla & Borneman, 1994 Marshall, 2006; Rice & Wexler, 1996). Perhaps this is due to the high phonological saliency of this morpheme? Inflecting a verb with *-ing* adds a whole syllable to the word, and that syllable is highly salient with regards to amplitude and duration (i.e. it is loud and long, relative to other morphemes such as past tense *-ed*). Indeed, the progressive *-ing* morpheme has been shown to be the first to be acquired (cf. Brown, 1973, de Villiers and de Villiers, 1973), indicating that it is one of the 'easiest' inflections in the English language. With these points in mind, it is unsurprising that children with SLI are unimpaired on this inflection, despite the fact that it denotes tense information.

Collectively, the data presented in this section highlight the gradient of difficulty with inflections children with SLI experience. It is clear from this data that the grammatical difficulties in SLI are selective, and seem to be relatively consistent across samples with the disorder. The literature seems to support Leonard's (2014) argument that it is verb morphology (tense/agreement in particular) that is most problematic for children with SLI (e.g. past tense and third person singular), as compared to other word classes such as nouns. This appears to be the case not only when children with SLI are compared to typically-developing children of the same age, but also to children who are younger but with a comparable language aptitude. However, the literature has shown that the progressive –ing inflection is unimpaired in SLI (e.g. Rice & Wexler, 1996), which is also a verb inflection that relates to tense. This then raises a paradox – verb inflections are the most affected, except the progressive inflection which is the least affected in SLI. Possible explanations for this paradox will be explored in section 1.3.3.2, which discusses phonetic saliency and the Surface Hypothesis, and builds upon the argument raised in this section regarding this morpheme's ease of acquisition.

It is interesting to note that the hierarchy of inflectional impairment seen in SLI somewhat mirrors the typical order of morpheme acquisition outlined in section 1.1.1. That is, the progressive *-ing* is the first and easiest to master for typically-developing children, and is the least affected in children with SLI. The regular plural is the next to be acquired, and is the next 'step' in the hierarchy of difficulty seen in SLI. The two verb morphemes are acquired later (at around the same time) and, although they are impaired to differing degrees in SLI, they are both rather problematic.

1.3.3.1 Types of inflectional morphology errors in SLI. With regards to specific errors in inflectional morphology, children with SLI are most likely to produce uninflected bare stems where there should be an inflected form ("zero-marking"), as compared to both age- and language-matched controls (e.g. Bishop, 1994; Leonard, 2014; Leonard et al., 1992; Oetting & Horohov, 1997). However, Rice et al. (2000) noted that the frequency of errors of overregularisation on irregular forms (e.g. runned) was comparable between children with SLI and their language-matched peers.

In addition, children with SLI are more likely than controls to judge bare-stem forms as grammatical in situations that require past tense inflected constructs (van der Lely & Ullman, 2001). This is further supported by Rice et al. (1999), who noted that children with SLI were more likely than chronological age matches to accept ungrammatical sentences as grammatical when morphemes associated with tense and agreement were absent, such as the regular past tense. This is compared to sentences in which manipulated morphemes did not serve a tense or agreement function, such as the plural inflection.

1.3.3.2 Why do verbs pose particular difficulty? In many languages, including English, verb learning appears to be more difficult than other word classes. Consequently, children acquire verbs later than other types of words, especially nouns which are attained very early in development (Bates et al., 1994; Caselli et al., 1995; Guasti, 2002). Children with SLI have exceptional difficulties with verb learning, resulting in smaller verb lexicons as compared to age- and language-matched controls (Conti-Ramsden & Jones, 1997; Hick, Joseph, Conti-Ramsden, Serratrice, & Faragher, 2002; King & Fletcher, 1993; Leonard, 2014). In addition, verb-noun dissociations are common in acquired language disorders, with verbs often being the vulnerable word class (e.g. Berndt, Haendiges, Mitchum & Sanderson, 1997; Zingeser & Berndt, 1990).

Keeping in mind the hierarchy of inflectional difficulty seen in SLI, it appears that it is verb inflections that are most problematic for these children (with the exception of the progressive –ing). On the contrary, noun inflections (such as the regular plural) remain relatively intact in the face of SLI. This mirrors the typical profile of difficulty as outlined in section 1.1.1 (i.e. the noun-verb dissociation): So what might make verbs so troublesome?

It has been suggested that the difficulty with verb learning in children with SLI may be caused by an inability to transfer newly-encountered verbs to long term memory. Rice, Oetting, Marquis, Bode and Pae (1994) studied the effect of frequency of input upon verb retention in children with SLI. They found that the short term learning of verbs could be enhanced by increasing the input frequency in both the SLI and age-matched groups, but that an increase of exposure to verbs could not ensure long term retention for the children with SLI. This was not the case in the chronological age controls, where there was a positive correlation between frequency of input and long term retention of verbs. However, Rice at al. (1994) did not assess the learnability of noun items, and so it cannot be concluded that verbs are harder for children with SLI due to an inability to transfer them to long term memory. In other words, Rice at al. (1994) cannot answer the question of what makes verbs particularly difficult; their findings only show that lexical items are less likely to be integrated into the lexicon in children with SLI.

Attempting to rectify this issue, Oetting, Rice and Swank (1995) directly compared the learnability of nouns and verbs. They found that children with SLI learnt less verbs than nouns, as compared to age-matched controls. In contrast, the learning of nouns was comparable between the SLI and control groups, giving more support to the idea that there is something intrinsically difficult about verb learning for children with SLI, over and above other word classes. If children have difficulty learning the items initially, it is not surprising that the associated morphology will also be difficult to learn.

Although Rice et al. (1994) and Oetting, Rice and Swank (1995) make some attempt at explaining the difficulty children with SLI have with verbs, their research does not answer the question of exactly *why* verbs pose more difficulty than other word classes. The issue remains of what exactly makes verbs more difficult to transfer to long term memory than nouns (for example).

There is a wealth of research that has reported that the frequency of verbs affects the performance of language-impaired children in grammatical tests (Leonard, Davis & Deevy, 2007). Specifically, it has consistently been found that children with SLI are more likely to correctly mark tense on frequently-occurring regular verbs, as compared to infrequently-occurring regular verbs (Marchman, Wulfeck & Ellis Weismer, 1999; Norbury, Bishop & Briscoe, 2001; Oetting & Horohov, 1997). Van der Lely and Ullman (2001) found past tense marking abilities of children with SLI was positively associated with the phonotactic frequency of both regular and irregular verbs. This was not found in the language-matched control group however, where frequency effects were only evident for irregular past tense forms. In addition, Leonard, Davis and Deevy (2007) found that children with SLI inflected high frequency novel verbs with the regular inflection *–ed* more often than low frequency novel stimuli. Interestingly, this was not true of the language- or age-matched controls where no effect of frequency was found.

In view of the literature presented above, it seems that children with SLI are highly sensitive to the frequency of verbs, and that this may moderate their grammatical abilities. This draws parallels with the typically-developing literature explored in section 1.1.1. However, it is unclear from the literature whether this is the case with nouns. Once again, studies have failed to directly compare verb and noun items. We know that children with SLI have inordinate difficulties with inflecting verbs, over and above that of nouns. Any explanation needs to encompass this, too, if it is to provide a comprehensive account of the disorder.

Chiat (2001) makes specific comparisons between verbs and nouns. She suggested that it may be difficulties with relative verb *phonology* which leads to the specific challenges with verbs seen in typical language, and the language of children with SLI. Chiat notes that verbs very rarely occur in isolation, as compared to nouns which are often presented as individual word forms to children. Chiat also notes that, when embedded within a sentence, verbs are less phonologically salient than the surrounding nouns. These phonological features of verb use in everyday language may explain why verbs are more problematic for children than other word classes (especially nouns).

Alternatively, it may be difficulties with verb *semantics* that can account for the challenging nature of verbs. As Chiat (2001) highlights, verbs convey a great deal of information about specific events, from specific points-of-view, which focus on specific participants. They are also brief in duration and are highly dynamic. It is these complexities that are not present in nouns that may explain the disadvantage children have with verbs.

Kelly and Bock (1988) examined 3000 English disyllabic nouns and 1000 English disyllabic verbs, and found that of the words with the stress on the first syllable, 90% were nouns. In contrast, of the words with the stress on the second syllable, 85% were verbs. Mattys and Samuel (2000) extended on from this research, and suggested that the non-canonical stress pattern of verbs might explain why they are harder to acquire than nouns. Mattys and Samuel (2000) experimentally demonstrated that even adults are sensitive to this stress-pattern difference, and concluded that words which do not have stress on the initial syllable will be more difficult to learn. They went on to argue that "non-initial stress words do indeed require additional processing, as suggested by costs in processing time, accuracy and memory load for these words relative to initial-stress words" (p. 588 as cited in Black & Chiat, 2003).

In addition to verb phonology, semantics and stress patterns, it has been suggested that the different ways in which verbs and nouns are learnt might help explain the dissociation. Marshall (2003) suggested that the learning of verbs and nouns may be *qualitatively* different. Marshall highlighted work by Goldfield (2000), which showed that young children who are in the early stages of learning their native language are usually asked to *produce* nouns (e.g. *"can you say dog?"*), but *comprehend* verbs (e.g. *"put it down"*). In addition, the work of Sandhofer, Smith and Luo (2000) showed that, in caregiver-child interactions, children are exposed to a large number of different nouns with only a few exemplars of each, whereas they are exposed to a small number of different verbs with many exemplars of each. These differences in learning situations might help explain why the two word classes can demonstrate dissociations.

It must be stressed that although the literature frequently demonstrates verb-noun dissociations, this does not imply separate linguistic stores (Bird, Howard & Franklin, 2000). Rather, the dissociation between nouns and verbs are best understood as a 'continuum of properties', which might encompass conceptual-semantic, syntactic and/or phonological components (see Bird et al., 2000 and Black & Chiat, 2003 for interesting debates surrounding this notion). Black and Chiat (2003) note that "the syntactic distinction between nouns and verbs goes hand in hand with phonological and semantic differences" (p. 231). They go on to argue that verbs are less salient than nouns and have a non-canonical stress pattern, resulting in increased difficulty segmenting them from running speech. This means that they are harder to perceive than nouns. Verbs' relative shortness in duration, lack of prosodic salience and increased grammatical complexity make them more difficult to store. All of these features combine, according to Black and Chiat (2003) to explain the verb-noun discrepancy. With this in mind, Black and Chiat argue against accounts that attempt to explain the discrepancy using a single property because a) individuals with language difficulties experience a 'mosaic pattern of aphasic performance'

(Berndt, Haendiges, Mitchum & Sanderson, 1997) that have not yet been fully explained by a single-property explanation and b) nouns and verbs have many related properties across a number of levels of processing, which make it impossible to truly disentangled the two.

Although the suggestions outlined in this section seem highly plausible as explanations for why verbs are more difficult to acquire than nouns, the question remains of why children with SLI show inordinate difficulties with verbs, as compared to age- and language-matched controls. The points raised only explain why verbs are more difficult than nouns to in all children; they do not explain why they are particularly difficult for children with SLI, over and above what is to be expected given their general language ability. This question will be revisited in sections 1.3.5 when theories of SLI will be explored, but for now a quote from Marshall (2003) seems especially fitting:

> *"The semantic and phonological complexities which delay normal verb learning should make verbs even more vulnerable in cases of developmental language disorder. Furthermore, if language is one route to verb meaning, a vicious circle may be established. A child who cannot segment phonology or retain word order will be unable to identify verb arguments or their sentence order. As a result, he will lack the information needed to unravel the meaning of many verbs. Yet, without these verbs, he is even less able to build linguistic contexts" (p. 70)*

1.3.4. SLI across languages. Before exploring various theories of the grammatical difficulties experienced by children with SLI, this section will briefly consider how SLI is manifested cross-linguistically. As Verhoeven and Balkom (2006) explain, "... a true explanation of grammatical impairment should encompass the symptoms that SLI entails in each and every language. An explanation that fails to do this is a descriptive generalisation that merely holds for the language it covers" (p. 264).

There is no universal impairment across languages in SLI (Leonard, 2014); rather it seems to depend on the complexities of the language in question. This chapter has repeatedly stressed that it is verb (and particularly tense) morphology that is most affected in children with SLI. However, whilst this is certainly the case in English-speaking children, it is not always true in children with SLI from other languages.

Although the specific pattern of deficits in children with SLI seems to vary across languages, it does appear that significant difficulties with nonword repetition are a common feature. For instance, it has been well-documented that poor nonword repetition skills (relative to both age- and language-matched controls) are a key feature of the language of English-speaking children with SLI (see Bishop, 1997 for a review). This is also the case in children with SLI whose native language is Dutch (Beers, 1992; Mulls, Pulles & Witten, 1992), Swedish (Sahl, Reuterski, Wagner, Nettelbladt & Radeborg, 1999), Italian (Junyent, 2011) and Spanish (Girbau & Schwartz, 2007, 2008), to name a few. The persistence of nonword repetition deficits in children with SLI across many languages suggests that the disorder may have roots in a phonological deficit. However, it is not known whether this is the primary difficulty, or whether there is a lower-level cognitive deficit that may be impacting upon phonological representations.

In addition to nonword repetition deficits, it appears that marking the past tense appears to pose particular difficulty for children with SLI from other languages. For instance, both de Jong (1999) and Spoelman and Bol (2012) found that Dutch children with SLI were less likely to produce past tense constructions in obligatory situations, as compared to both age- and language-matched controls. Hansson, Nettelbladt and Leonard (2000) found that Swedish children with SLI made more errors pertaining to the past tense in spontaneous speech samples, as compared to age- and language-matched controls. Finally, the findings of Lum and Bleses (2012) showed that Danish children with SLI were impaired in the use of the past tense, as compared to age-matched controls.

It has been shown that, like English-speaking children with SLI, children from other languages demonstrate significant difficulties when using the past tense. These languages include Dutch, Swedish and Danish, as well as German

(Clahsen,1992). Note that all of these languages are Germanic in origin, and so they share some fundamental structures, particularly with regards to verb arrangements. In contrast, children whose native language has a Romance origin do not seem to show such deficits. Indeed, some studies have directly compared English-speaking (Germanic) children with SLI to Italian-speaking (Romance) children with SLI of the same age, and showed that both noun and verb inflections were much less impaired in the Italian children (e.g. Bortolini et al., 1998; Leonard, Sabbadini, Leonard & Volterra, 1987).

Instead of past tense deficits, children speaking Romance languages appear to have the most difficulty with unstressed direct object pronouns (Leonard, 2000). This has been shown in children whose native language is Spanish (Bedore & Leonard, 2001), Italian (Bortolini et al., 2006) and French (Jakubowicz, Nash, Rigaut & Gerard, 1998).

It appears that the area of language that poses the most difficulty for all children with SLI, regardless of their native language, seems to be determined by phonological properties. The past tense is very weak in phonological salience in Germanic languages, and the difficulties in Romance languages are associated with *unstressed* pronouns (again, weak in phonological salience). The notion that it is the phonological properties that determine affectedness is further supported by the work of both Cipriani et al., (1991) and Sabbadini, Volterra, Leonard, and Campagnoli (1987), who found that Italian-speaking children with SLI were worse than both age- and language-matched controls in the use of function words such as articles and clitics. These are two of the weakest aspects of the Italian language, phonologically-speaking (Leonard, 2014). Finally, the demonstration that nonword repetition deficits in SLI are consistent across most languages further supports the proposal that it is phonology that determines degree of affectedness, as the nonword repetition task is one of the purest measure of phonological aptitude (e.g Archibald & Gathercole, 2007).

Despite the above literature suggesting it is phonological properties that determine *what* is affected in SLI, it does not answer the question of *why* these aspects of language are affected in SLI. Indeed, this thesis aims to investigate whether general cognitive limitations can help explain the deficits seen in SLI.

1.3.5. Linguistic and cognitive theories of inflectional morphology difficulties in SLI. Despite knowing a great deal about the difficulties children with SLI experience, the aetiology of SLI remains unclear. There are many theories in the literature that attempt to explain the cause(s) of SLI, and that try to account for the specific profile of inflectional difficulties seen in the disorder. Broadly speaking, theories that attempt to explain the specific grammatical difficulties seen in SLI fall in to one of two domains: linguistic or cognitive. Linguistic theories argue that language and grammar are represented in a modular fashion in the brain (Fodor, 1983), and as such it is a system independent of other cognitive functions. Linguistic SLI theories argue that the inflectional deficits in the disorder are the result of an impairment within the grammatical 'module', and is best thought of as a failure to develop the grammatical rules of one's native language (e.g. Gopnik & Crago, 1991).

In contrast, cognitive theories of SLI argue that a more domain-general in information processing skills can account for the impairments in inflectional morphology, rather than a specific grammatical deficit. In view of this, cognitive theories of SLI predict that any grammatical deficit will be underpinned by a deficit in more general cognitive skills.

1.3.5.1 Linguistic accounts. Section 1.1 described how Pinker's Dual Route model (e.g. Pinker & Prince, 1988) proposed two paths to grammatical development; the rule-based path which deals with regular lexical items, and the memory-based, associative path which handles the learning of irregular items. Gopnik and Colleagues (e.g. Gopnik & Crago, 1991; Ullman & Gopnik, 1994) have taken the Dual Route model and have proposed the Implicit Rule Deficit account to try and explain the grammatical deficits seen in children with SLI. This account argues that children with SLI have impairment in the system that learns inflectional regularities (the rule-based route) and consequently have difficulty learning morphological rules. The children therefore rote-learn past tense constructions as though they are all irregular (i.e. using a word-specific paradigm), and store each regular form as an entire module, as opposed to a stem and a suffix.

The Implicit Rule Deficit account of SLI makes some testable predictions: Firstly, errors of overgeneralisation would not occur if this theory holds true, as children are apparently impaired in the learning of regularised rules. In addition, this account would predict that children with SLI demonstrate difficulties with all regular inflections, verb or otherwise. However, the literature presented thus far refutes these two predictions. It has been demonstrated that children with SLI do indeed overgeneralise, and suffix regular inflections on to irregular items to the same extent as typically-developing controls. In addition, it has been shown that not all regular morphological items are impaired in SLI. For instance, the regular plural inflection is relatively robust, and the present progressive morpheme appears to be completely unimpaired (see Bishop, 2014 for an overview). The Implicit Rule Deficit account cannot explain the hierarchy of inflectional difficulty (i.e. past tense is most affected, third person is moderately impaired, progressive is unaffected) that has been shown time and time again in children with SLI (see Leonard, 2014 for an extensive review of the literature). In view of these two points, it seems unlikely that the Implicit Rule Deficit account can adequately explain the grammatical deficits seen in children with SLI.

An alternative linguistic account of the inflectional difficulties seen in SLI is the Extended Optional Infinitive account of Rice and her colleagues (e.g. Rice & Wexler, 1995; Rice, Wexler & Cleave, 1995). This account is based upon the view that in typical development, children experience a stage of treating verb inflections (and specifically, the marking of finiteness) as optional, as opposed to obligatory. The assumption is that children have the knowledge and capability to apply grammatical morphemes to verbs, but that initially they do not understand (be that explicitly or implicitly) main clauses always require the marking of tense. This leads to a fluctuation between the use of marked and unmarked verbs in obligatory situations. Typically-developing children soon begin to understand (explicitly or otherwise) that tense marking is necessary in spoken constructions, and consequently pass through this ‘Optional Infinitive stage’. This theory argues that children with SLI are delayed in using obligatory tense marking, and therefore stay in this stage for longer than their peers. As a result, verb inflectional errors are seen in SLI, but are not seen in typically-developing children of the same age.

The Extended Optional Infinitive account makes an interesting prediction: children with SLI should only have deficits in tense marking; grammatical morphemes unrelated to tense (e.g. the regular plural –*s*) should be unaffected. However, some studies have showed a small, but significant deficit in the regular plural –s (e.g. Conti-Ramsden & Windfuhr, 2002; Leonard et al., 1992). In addition, it has consistently been shown that the progressive *-ing* inflection is unimpaired in SLI (e.g. Conti-Ramsden & Windfuhr, 2002; Bishop, 2013; 2014), which is a tense marker. Both of these lines of literature weaken the Extended Optional Infinitive account of SLI. Furthermore, the Extended Optional Infinitive account cannot explain the differential levels of inflectional impairment in SLI, even within the tense morphemes. That is, it cannot explain why the regular past tense is more affected in the disorder than the third person singular inflection.

In view of the critical points raised in this section, it appears that linguistic accounts struggle to fully explain all facets of the inflectional morphology deficits experienced by children with SLI. This section will now move on to exploring the cognitive accounts, to investigate whether these can adequately explain the difficulty with morphology that children with SLI face.

1.3.5.2 Cognitive accounts of SLI. If SLI is the result of a general cognitive deficit, then we would expect children to show impairment in at least one basic cognitive function, alongside their more specific language difficulties. Upon examining the evidence, there does appear to be some significant support for the idea that children with SLI do indeed demonstrate problems with more general cognitive systems.

There are several cognitive deficit hypotheses proposed in the literature. The most prominent approaches will be explored in the following section: Speed of information processing, [the Surface Hypothesis], auditory processing deficit and phonological memory deficits.

1.3.5.2.1 Speed of information processing. One hypothesis within the speed of processing account of SLI is the Rapid Auditory Processing Deficit hypothesis, which is largely influenced by the work of Tallal and colleagues (e.g. Tallal & Piercy, 1973). Tallal and Piercy (1973) conducted an Auditory Repetition Task (ART) using children with SLI and age-matched controls. In the ART, children first experience a training phase, whereby they learn to associate two different auditory tones with pressing two different buttons (i.e. button 1 is pressed when tone 1 is heard; button 2 is pressed when tone 2 is heard). Children then complete the experimental phase of the ART. In this phase, children are presented with two-tone patterns using the trained sounds and are required to copy the order by pressing the appropriate buttons. Tallal and Piercy found that children with SLI performed significantly worse than controls when the tones were brief in duration (75ms), and the inter-stimulus interval was relatively short (150ms or less). It was concluded that the language difficulties seen in children with SLI may be attributed to a 'temporal processing deficit', which is specifically associated with rapidly-changing auditory information (such as every-day speech).

Tallal and Piercy (1974) later support their original work by showing that children with SLI were significantly worse than controls at distinguishing (by means of button presses much like the ART) between phonemes whose voice onset time differ only in the very first few milliseconds (such as /ba/ and /da/). Conversely, the SLI group performed similar to controls when the two phonemes had longer comparative voice onset times (and thus were not as 'rapidly-changing'). Other experimental work has also reported a deficit in the ART in children with SLI when the inter stimulus interval was short and tones were brief in duration (e.g. Ludlow, Cudahy, Bassich & Brown, 1983, Tallal, Stark, Kallman & Mellits, 1981). In addition, studies have shown children with SLI perform poorly on non-verbal tests involving rapidly-presented auditory information. For instance, Tallal and Piercy (1973) noted that children with SLI were worse than controls at discriminating between two rapidly-presented tones that differed in pitch only. Visto, Cranford and Scudder (1996) found that children with SLI struggled to track the spatial location of auditory tones when they were presented rapidly, but not when they were presented slowly. Finally, Ludlow et al. (1983) noted that children with SLI struggled to detect short pauses in bursts of sound, but typically-developing children had no such difficulty. Combined, all of this evidence suggests that children with SLI may have a problem with processing rapidly-presented auditory information, and that this is not restricted to the linguistic domain.

However, whilst there seems to be a good amount of evidence for a rapid temporal processing deficit, there also appears to be a large body of evidence suggesting children with SLI have no such deficit. For instance, Bishop et al.

(1999a) found that children with SLI performed as well as controls at detecting a brief tone in a backwards auditory masking paradigm. Helzer et al. (1996) noted that children with SLI performed as well as controls in tasks measuring brief tone-in-noise detection and brief silence-in-noise detection. Norrelgen et al. (2002) also found SLI were comparable to controls in a same-different task using rapidly-presented tones. In addition, Bishop et al. (1999b) noted that children with SLI performed worse than controls on the ART task for stimuli presented at all rates; poor performance was not restricted to rapidly-presented auditory stimuli. A similar finding has also been found by Lincoln et al. (1992).

If SLI was the result of impairment in rapid temporal processing, then we would see all children with such a deficit to show SLI-like behaviour, and all children with SLI to demonstrate rapid temporal processing issues. This does not seem to be the case however. Some typically-developing children experience temporal processing deficits (Bishop 1999a), and some children with SLI show no such auditory deficit (Bailey & Snowling, 2002). In addition, any temporal auditory processing deficit that is present in SLI does not predict much variance in language-impaired samples (Rosen, 2003). Finally, Ziegler et al. (2005) noted that children with SLI demonstrated deficits in spectral processing, as well as temporal, suggesting the auditory deficit in SLI extends beyond the temporal domain (see section 1.3.5.2.3 for further information on temporal versus spectral processing).

There is clearly much contradiction within the literature surrounding a fast temporal processing deficit in SLI. It may be that, given the extensive hetereogeneity within the SLI population, only a sub-group of children with SLI have a rapid auditory processing deficit (McArthur and Bishop, 2001; Farmer & Klein, 1995). Alternatively, it may be that the auditory deficit is a more general and fundamental one, rather than being restricted to fast stimuli for children with SLI. That is, children with SLI may experience ‘generalised slowing’, which impacts upon their inflectional morphology skills.

Although not part of the clinical diagnostic criteria, a generalised ‘slowness to process’ often features in the clinical reports of children with SLI (Montgomery, 2002). This is reflected in the literature; there is a substantial body of evidence to suggest that children with SLI have deficits in general speed of processing, rather than only problems with rapidly-presented stimuli. This seems to be the case in both linguistic and non-linguistic tasks. For instance, children with SLI show slower performance than their age-matched peers in tasks of peg moving and bead threading (Bishop, McDonald, McDonald & Brookman, 2013; Powell & Bishop, 1992), basic auditory reaction times (Townsend & Wulfeck, 1995) and mental shape rotation (Johnston & Ellis Weismer, 1983). Children with SLI are also slower than their peers in measures of nonword learning and fast-mapping of linguistic items, especially when stimulus presentation rate is increased (Weismer & Hesketh, 1996). Picture naming speed is also impaired in SLI (Lahey & Edwards, 1996), and Montgomery (2000) found that children with SLI were slower than age-matched controls when performing lexical decision and word monitoring tasks. The slower processing of children with SLI remains to be the case not only when compared to chronological-age controls, but also to younger typically-developing children who have comparable language skills (e.g. Montgomery & Leonard, 2006; Montgomery et al., 2008).

The speed of processing impairment in SLI appears to be present in not only behavioural domains, but also electrophysiological. For instance, Weber-Fox, Hart and Spruill (2006) conducted an event-related potential study with adolescents with language impairment. It was found that these children showed delayed N100s (an evoked potential that occurs shortly after the onset of a stimulus (Spreng, 1980)) elicited by short tones, as compared to age-matched controls. This indicates that even very basic levels of processing, where there are limited working memory demands, are speed-impaired in children with SLI.

Kail (1994) supports the notion that the difficulties children with SLI experience are the result of ‘generalised slowing’. Here, it is suggested that children with SLI are slower to perform all constituent aspects of a task by a proportionate amount. For instance, a basic word recognition task requires storage of the target word, auditory perception of the options, recognition of the target word, rejection of the foils, and articulation of the answer. The generalised slowing hypothesis argues that a child with SLI is consistently slower than a typically-developing child to conduct each element of the task, resulting in a slower overall response time.

Kail's meta-analysis (Kail, 1994) showed children with language impairment to be 33% slower across both linguistic and non-linguistic tasks. Windsor and Hwang (1999) also conducted a similar meta-analysis, but reported a slowing rate of 18%. Miller, Leonard and Tomblin (2001) further investigated the generalised slowing hypothesis in a more experimental way. They studied the same group of children with SLI and looked at their performance on a wide range of timed tasks (linguistic and non-linguistic). It was reported that the slowing speed was approximately 14%. All three analyses presented here managed to explain approximately 95% of the variance in task performance between the children with SLI and their typically-developing counterparts when taking into account the generalised slowing percentages.

There are numerous differing hypotheses suggesting the inflectional difficulties in SLI are the result of a general speed of processing deficit. Although the specifics of each hypothesis vary, they all share the view that SLI is the result of a problem with the time it takes to perceive, integrate and store incoming stimuli, rather than the stimuli's nature itself (see Bishop, 1992). For instance, Leonard et al. (2007) argued children with SLI may well be capable of understanding that, for example, suffixing *–ed* to a regular verb places the action in the past tense. However, they may be unable to process the auditory signal fast enough in order to perceive the inflection and then make an inference as to its purpose and store it into an inflection paradigm, all in sufficient time before the next element of the incoming speech signal needs to be processed.

There is a small body of experimental literature demonstrating that when stimulus presentation rate is slowed, children with SLI show improved performance on tasks assessing inflectional morphology skills (e.g. Montgomery, 2005). The link between the rate of stimulus presentation and the performance of children with SLI extends past the grammatical domain. For instance, Ellis Weismer and Hesketh, (1996) found that children with SLI learnt fewer nonwords than chronological-age matched controls when they were presented at a fast rate during learning, but a comparable rate when sentences were presented at a normal rate. This supports the argument that children with SLI are more sensitive than their peers to the speed with which information is presented. Montgomery (2004) noted that sentence comprehension of children with SLI was comparable to children with matched receptive syntax skills when sentence presentation rate was slowed by 25% (although they still remained worse than age-matched controls; performance was impaired relative to both control groups when sentences were presented at a normal rate). In addition, Fazio (1998) found that children with SLI had serial recall abilities comparable to age-matched controls when items were presented at a slower rate, but worse than controls when items were presented at a normal/baseline speed.

1.3.5.2.2 The Surface Hypothesis. It has been well documented that children with SLI are likely to experience generalised slowing. The question remains however of how exactly can generalised slowing account for the specific inflectional deficits seen in SLI? One possibility is that the processing of sentence-embedded inflections is more time-dependent than other aspects of sentence processing. That is, inflections are brief in duration and so are highly time-dependent, and as a result may be the most likely to become impaired in the face of a speed of processing deficit. Thus, impairment in speed of processing (i.e. generalised slowing) may result in impaired inflectional awareness, leading to weak grammatical representations (Miller, Leonard, & Tomblin, 2001).

Building on deterthe speed of processing accounts of SLI, Leonard and his colleagues have suggested an interaction between the phonetic properties of a morpheme and a child's processing speed ability in their 'Surface Hypothesis' (e.g. Leonard, 1989; Leonard et al., 1997). This 'hybrid' theory between the linguistic and cognitive domains argues that a child with SLI processes incoming information slower than their typically-developing peers, which leads to morphemes particularly brief in duration and low in phonetic substance to be passed over during sentence processing. Low phonetic substance is defined in terms of relative duration, but amplitude is also suggested to play a part. Such morphemes include consonant inflections such as past tense –ed and third person singular –s (Montgomery & Leonard, 2006). Leonard goes on to argue that a child with SLI is more likely to abandon processing of such brief and low phonetic substance morphemes, as they struggle to process real-time language effectively and need to 'skip' parts of a sentence to process its meaning in adequate time. To clarify, it is not suggested that children with SLI cannot process low phonetic substance morphemes, rather these morphemes require more processing effort due to their phonological properties and so are most likely to be processed fully less often in children with SLI; this may result in less well-developed representations of these morphemes.

Leonard's Surface Hypothesis is strengthened when we assess what inflections English-speaking children with SLI struggle with. In English, the regular past tense *–ed* and the third person singular *–s* inflections are particularly problematic for children with SLI. Both of these morphemes have relatively low phonetic substance as compared to the words surrounding them in a sentence. In contrast, the progressive inflection *–ing* is usually unimpaired in SLI, and it does have much more phonetic salience than the regular past tense and third person singular. Thus, despite being a verb inflection (that is notoriously difficult for children with SLI to master), its comparatively high phonetic saliency may protect it from becoming impaired in SLI.

Further support for the surface hypothesis comes from cross-linguistic research (Leonard, 2014); a particularly neat contrast is between English and Italian languages. For instance, English-speaking children with SLI show difficulty when using the articles *the* and *a* – items that are low in phonetic saliency when used in every-day running speech. Italian-speaking children with SLI only seem to have difficulty with articles when they are low in phonetic saliency. Leonard (2014) noted that Italian-speaking children with SLI correctly used high-phonetic saliency articles (*la, una, I*) 74% of the time, but only 7% of the time when the articles were low in phonetic saliency (*il, un*). This demonstrates that it is not necessarily the grammatical function of morphemes that determines their affectedness; rather it may be their phonological properties.

The Surface Hypothesis is further supported by computational modelling work. Hoeffner and McClelland (1993) created a model whereby an artificial language was learnt that contained verb stems and inflections. The morphemes in the model varied in phonetic saliency (as is the case in English), which were represented as having less strength in the model. SLI was 'induced' in the model by giving weaker representations to all phonemes, therefore making the lower phonetic saliency ones even weaker. The model successfully simulated a range of morphological deficits as seen in SLI; specifically, third person singular and past tense inflections were more affected than the present progressive. Errors in the model manifested as an increase in the production of bare stems where an obligatory inflected form was required, which is the most common error seen in the productions of children with SLI (Rice & Wexler, 1995).

The surface approach does not fully account for a lack of impairment in some low phonetic substance morphemes in SLI in English, such as the regular plural –*s*, although Leonard (1998) does argue that two phonetically identical morphemes (e.g. plural -*s* and third person singular -*s*) may be acquired at different times according to their grammaticizability (following Slobin, 1985). That is, the Surface Hypothesis does not exclude grammatical complexity as part of the explanation for why some inflections are harder than others, but instead argues that surface features (such as phonetic salience) are also important. This may be part of the explanation for why third person singular is later acquired and more problematic in SLI than plural –s. Nonetheless, the emphasis of the Surface Account is on the role of phonetic salience, and work by Hsieh, Leonard & Swanson (1999) suggests that even morphemes that are phonologically equivalent (such as the two types of –s) may vary in phonetic substance according to context. This study noted that the regular noun plural is most commonly found in sentence-final positions during (English) mother-child exchanges. Phonemes that occur in sentence-final positions are significantly lengthened, as compared to when they occur in the middle of a sentence. In contrast, Hsieh, Leonard and Swanson (1999) noted that, in mother-child interactions, the third person singular inflection is rarely found in a sentence-final position, and so does not get such sentence-final lengthening. This may account for the differential levels of impairment between the third person singular and regular plural –*s* inflections, and once again supports the idea that it is the relative phonetic properties of the inflections that determines their severity of impairment.

Montgomery and Leonard (1998) explicitly tested the idea that the phonetic substance of morphemes determine how impaired they are in SLI. Children with SLI (mean 8 years 6 months) were compared to chronological age matches using both grammaticality judgement and word monitoring tasks. The specific inflections under investigation were: the third person singular (low phonetic substance), regular past tense (low phonetic substance) and the progressive (high phonetic substance). The -*s* and the -*ed* morphemes were collapsed into one 'low phonetic substance' group. The children with SLI were comparable to controls in both tasks with regards to their awareness of the progressive inflection. For the two low phonetic substance morphemes however (*-s* and *-ed*), children with SLI were impaired on both the grammaticality judgement and word monitoring task, as compared to the control group. The authors concluded that it is the phonetic substance of the inflections that determines their affectedness.

However, Montgomery and Leonard (2006) argue their 1998 findings are confounded by the argument that age of acquisition and grammatical function are important. The progressive morpheme is one of the earliest to be acquired by both typically-developing children and those with SLI; this is likely to be because it is a relatively 'easy' inflection on phonological and articulatory dimensions, and one whose grammatical function can be identified easily (Montgomery & Leonard, 2006). Therefore, it is unclear whether the progressive inflection was unimpaired due to its high phonetic substance, or its clear grammatical function and early age of acquisition. In addition, the relative impairment between the two low phonetic substance markers cannot be assessed from Montgomery and Leonard (1998), as they were combined into one variable before any analyses had taken place.

Montgomery and Leonard (2006) attempted to rectify these shortcomings by replicating their earlier study, but adding the comparative *er* – inflection; this morpheme is high in phonetic substance but it does not have a particularly early age of acquisition. Analyses were also conducted on individual inflections. In addition, the authors also enhanced the phonetic saliency of the low phonetic substance morphemes by means of verbally increasing their relative duration and amplitude, with the hope that this would improve the children with SLI's performance on both the grammaticality judgement and word monitoring tasks. It was argued that if children with SLI are indeed slower to process incoming stimuli, increasing the duration and amplitude should facilitate perception of the morphemes. Montgomery and Leonard (2006) also argue that their 1998 findings were confounded by the inflections being tied exclusively to tense and agreement – grammatical functions that children with SLI are especially impaired with, regardless of phonetic substance (Rice & Wexler, 1996). Therefore, it is unclear from the 1998 findings whether it was phonetic substance or grammatical function that was important. Montgomery and Leonard's (2006) later study also sought to rectify this issue by including a nontense/nonagreement morpheme – the possessive *–s*. By comparing this inflection to the third person singular, the authors were able to assess the independent contributions of phonetic saliency and grammatical function.

Montgomery and Leonard (2006) conducted grammaticality judgement and word monitoring tasks with children with SLI (mean age 9 years 0 months) and chronological age-matched controls (mean age 8 years 11 months). The inflections under investigation were the third person singular (low phonetic substance), the possessive (low phonetic substance), the progressive (high phonetic substance) and, for the grammaticality judgement task only, the comparative (high phonetic substance). The authors further manipulated the phonetic saliency of the morphemes experimentally, such that they were either produced naturally or acoustically-enhanced. Acoustic enhancement was achieved by verbal exaggeration of duration and amplitude of the morpheme during stimuli recording.

For the grammaticality judgement task, children with SLI were worse than the controls at detecting ungrammaticality across the board. The children with SLI had weaker performance on the low phonetic substance markers than the high phonetic substance ones; no such differential performance was seen in the control group. This is consistent with the earlier findings of Montgomery and Leonard (1998). There was no difference in performance between the two low phonetic substance (third person singular and possessive) inflections for the children with SLI; they were equally-impaired on these two morphemes. In addition, there was no difference in performance between the SLI and control groups for the progressive inflection, indicating children with SLI are unimpaired in this morpheme. Verbal acoustic enhancement did not affect the chronological age-matched group's performance (although this is likely to be due to ceiling effects), but it significantly improved the grammaticality judgement performance of the children with SLI, particularly when the morphemes were low in phonetic substance. The children with SLI experienced great difficulty with the comparative morpheme, but their age-matched peers had adequate levels of performance.

In the word monitoring task, all children responded to the target words faster when they occurred in grammatical sentences, as compared to ungrammatical ones. In addition, children with SLI had slower overall reaction times, as compared to their age-matched peers. This demonstrates the standard task paradigm, and highlights that the task is an appropriate measure of grammatical awareness in both typically-developing and language-impaired children. Overall, reaction times were faster when the morpheme was high in phonetic substance, as compared to low phonetic substance. There was no significant difference in performance between the two low phonetic substance markers (third person singular -*s* and possessive -*s*). Although the children with SLI did show a grammatical-ungrammatical reaction time discrepancy when the morpheme had high phonetic saliency, this was not evident in the low phonetic substance morphemes, where there were no reaction time differences as a function of grammaticality (indicating a lack of grammatical awareness for these inflections). This again replicates the authors' previous findings (Montgomery & Leonard, 1998). For the typically-developing children, a grammatical-ungrammatical reaction time discrepancy was evident for all inflections under investigation.

With regards to the acoustic enhancement, word monitoring task performance was not altered for any morpheme for the children with SLI as a function of increased saliency. This was the general pattern seen in the control group too, with the exception of the progressive inflection where reaction times were significantly *slowed* as a result of the acoustic enhancement, as compared to the natural voicing of the inflection. This is presumably because the longer duration of the morphemes led to added temporal demands and/or a loss of attention in the typically-developing group (Montgomery & Leonard, 2006).

The finding that an increased phonetic saliency does not lead to better word monitoring task performance in this study is surprising, especially when one considers the findings from Montgomery (2005). Montgomery (2005) noted that children with SLI showed significantly better word monitoring task performance when the stimuli articulation rate was slowed by 25%. Montgomery and Leonard (2006) argued this unexpected result was because the processing deficit in their children with SLI was too great, and that, despite the increased saliency, they were still unable to complete all of the required operations for the word monitoring task in a timely manner. This argument appears to stand strong when we assess the grammaticality judgement findings from the study; phonological saliency enhancement did help in this task as children were given time to process and reflect upon the sentence, rather than having to do it in real time.

In view of the evidence presented in this section, it does seem plausible that the Surface Hypothesis may be an appropriate explanation for the grammatical difficulties experienced by children with SLI. That is, their slower speed of processing may interact with the phonological properties of inflections to determine levels of inflectional difficulty. However, there is a large bank of strong evidence suggesting impairments in other cognitive domains can also explain the specific hierarchy of inflectional difficulty, which cannot be ignored.

1.3.5.2.3 Auditory processing. Another possible explanation for the inflectional deficits seen in SLI relates to hypotheses surrounding impaired auditory processing (e.g. Merzenich et al., 1996; Tallal et al., 1996). Here, it is suggested that children with SLI have some form of impairment with low-level auditory perception, which negatively affects a child's speech perception, and consequently language development. As such, it has been argued that children with SLI have impairments with the quality of auditory input and/or processing speech-in-noise. Before discussing these possibilities, the general mechanisms behind typical language processing from an auditory perspective need to be understood.

For accurate speech perception, one must assess several features of the incoming speech signal including spectral shape, amplitude modulation and temporal resolution of both the slow changes within the incoming signal and the fast consonantal articulatory changes. The listener must also disregard redundant background noise (e.g. other speech) efficiently and extract the important sound information. The development of these skills begins in utero, and by 6 months of age a child can demonstrate adult levels of frequency detection (i.e. adequate spectral processing skills) and relatively good temporal extraction skills (Bailey & Snowling, 2002).

A large number of theories and empirical research into language processing are based upon conditions of "artificial normality" (Mattys & Liss, 2008), in which participants are required to process language under optimum listening conditions (a silent room, a sound signal that has been carefully recorded and is pronounced clearly, no distractions to attention etc). As Mattys et al. (2012) argue, speech perception in everyday life is rarely carried out under these optimum conditions. Instead, there are a whole host of factors that cause suboptimal, or adverse, listening conditions, which vary with regards to their origin. Mattys et al. (2012) argue that there are three key origins of adverse listening conditions: Source degradation, environmental/transmittional degradation and receiver limitations. These will be briefly discussed in turn.

Source degradation refers to "any intrinsic variation of the speech signal leading to reduced intelligibility compared to speech carefully produced by healthy native speakers" (p. 954). The term 'intrinsic' here refers to degradation of the speech itself, rather than degradation of the communication channel (e.g. a noise mask). One factor that can result in source degradation is oddities within conversational speech (e.g. syllable deletion and segment reduction) and a faster speech rate of the talker. Other factors include a talker's accented speech or a speech disorder within the talker, which can both degrade the intelligibility of the speech signal, as compared to healthy native speaker speech.

Environmental or transmissional degradation can also lead to adverse listening conditions, which in turn may negatively affect language processing. Whereas with source degradation the issues lie intrinsically within the speech signal itself, environmental or transmissional degradation sees faults in the wider communication channel. Factors which can result in environmental or transmissional degradation most commonly involve competing signals in the environment, such as background noise causing the critical signal to be 'masked'. As Mattys et al. (2012) highlight, when considering competing signals such as noise masks, it is important to note whether that mask is 'energetic' in nature, or not. Masks that are energetic in nature carry a physical overlap to the underlying critical signal, such as white noise or competing background talkers (see Brungart, 2001 for a review). This is in contrast to non-energetic masks which impair the source without being a signal in their own right, such as telephone transmission filtering (e.g. Nilsson & Kleijn (2001) demonstrated that most telephone transmissions filter out frequencies below 400Hz and above 3400Hz, which is mostly outside of the 100-5000Hz range at which human speech carries information (Borden, Harris & Raphael, 2007)). When a speech signal is masked by an energetic masker, one needs to call upon their signal separation and selective attention skills in order to process the underlying target (Darwin, 2008).

Within the energetic masking category, the amplitude of the masks can be either fluctuating or constant. If the mask's amplitude envelope is fluctuating, a listener can make use of the parts of the mask that are lower in amplitude in order to hear 'glimpses' of the underlying critical speech signal, which can help maximise comprehension, as compared to a stationary noise mask (Festen & Plomp, 1990; Summers & Molis, 2004). In contrast to fluctuating noise masks, some energetic masks can have constant amplitudes, such as steady-state noise. If the noise mask grasps the attention of the listener, or causes semantic interference with the underlying speech signal, or increases cognitive load, it is said to be an 'informational' mask (Kidd, Mason, Richards, Gallun & Durlach, 2007).

The final factor that can lead to adverse listening conditions outlined by Mattys et al. (2012) is that of limitations within the receiver (be that perceptual or cognitive). Within this category, Mattys et al. (2012) argue that there are four factors: Firstly, a receiver could have 'peripheral deficiencies', such as hearing loss. Alternatively, a receiver could have an 'incomplete language model': this could result from inadequate phonological, lexical or grammatical representations of the language that the critical signal is in. Individuals could also have 'impaired access or use of the language model', such as aphasia or deafness. Finally, receivers could have limitations with 'cognitive load', such as attentional or working memory challenges. Mattys et al. (2012) highlight that, although cognitive load often originates in the environment (e.g. a secondary task that requires divided attention), it is identified as a receiver limitation because the degree to which they affect speech processing is dependent on the receiver's individual cognitive capacity. That is, a child with poor working memory who struggles more on a language processing task than a child with excellent working memory does so because of limitations within them, not extrinsic to them.

It is important to note that although Mattys et al. (2012) have proposed three very distinct factors that could cause adverse listening conditions, these are not stand-alone components. Indeed, the factors can combine to degrade the speech signal further. For instance, Mattys et al. (2012) provide the example of a non-native receiver listening to speech-in-noise (speech perception of non-native receivers is more affected than native receivers e.g. Rogers, Loser, Febor, Besing & Abrams, 2006). Here, an incomplete language model and environmental degradation combine to further detriment speech processing.

Mattys et al. (2012) also note that "perceptual degradation of speech has been proposed as a means of simulating [impaired access or use of the language model] in healthy listeners … [which] might suggest commonalities between behavioural profiles induced by source or environmental degradation and receiver limitations" (p. 958). This is a very interesting and important point, and one which forms the backbone of this thesis' methodology and theoretical standpoint. That is, can one simulate receiver limitations by degrading the source or the environment/transmission?

Building on from Mattys et al's (2012) theory-driven paper, there is a solid bank of literature which experimentally manipulates the auditory quality of the speech signal. That is, they introduce environmental degradation, which stresses participants' general cognitive systems. In an early cognitive stress study, Kilborn (1991) used pink noise (noise on the speech spectrum) to partially mask auditory stimuli, and therefore degrade the perceptual quality of the input. Kilborn tested the effect of the noise mask on the awareness of word order and agreement in typically-developing German and English participants. In German, agreement is more important for sentence comprehension than it is in English; word order is more crucial to comprehension in English than German. The noise mask eliminated the awareness of agreement in English, and significantly impaired it in German. The noise mask did not affect word order processing – in fact, participants began to rely *more* on word order in the noise condition to help aid comprehension. This early study gives promise to the idea that a noise mask can account for impairments in grammatical processing.

Kilborn's results have since been supported. Leech, Aydelott, Symons, Carenvale & Dick (2007) investigated the effect of cognitive stress on participants' sentence comprehension. The cognitive stress conditions included attentional demands, auditory masking and semantic interference. It was found that of the three stressors, auditory masking had the most significant impact on sentence comprehension, especially for the more complex sentence structures. Given that sentence complexity is a grammatical feature, this research highlights a possible link between auditory perception and grammatical processing.

Work by Ziegler et al. (2005, 2011) has built upon the noise masking literature in great detail, and has provided a good amount of evidence to suggest that SLI may indeed be the result of a general auditory perception deficit. In their 2005 study, Ziegler et al. investigated the nature of speech perception deficits in SLI in 'ecologically-valid' (noisy) listening conditions. They tested French children's (SLI mean age 10.4years, language match group mean age 8.6years, age matched group mean age 10.6years) ability to detect consonantal categories under optimal (silent) and masked noise conditions. It was a forced-choice task, whereby participants heard vowel-consonant-vowel sequences and had to choose from a visual display what they just heard. There were two types of noise mask used: temporally-fluctuating and stationary. Both noise masks were on the same spectrum as running speech; that is, they were pink noise. It was found that in the control (silent) condition, children with SLI were worse at consonantal perception than their age-matched peers, but were comparable to their language-matched peers.

When looking at the fluctuating and stationary noise as individual elements, Ziegler and colleagues found children with SLI to have worse consonantal category detection than both age- and language-matched controls in both noise conditions. This suggests that children with SLI are more affected by noise than their typically-developing peers, even when language ability is considered. An analysis of scatter plots revealed the vast majority of their SLI sample evidenced some level of significant auditory perception deficit. In addition, regression analyses showed speech perception deficits to significantly predict severity of language performance on both real word and nonword repetition tasks. Considering all of these points, issues with speech-in-noise processing may indeed be a cause, rather than a consequence, of the language impairment in SLI.

The findings of Ziegler et al. (2005) contradict some studies that dispute a wide-spread auditory deficit in SLI samples e.g. Bailey & Snowling, 1992; Rosen, 2003). However, as Ziegler and colleagues point out, the majority of studies that investigate speech perception and find no deficit do so under optimal listening conditions. As the aforementioned research has found, it is speech-in-noise that children with SLI may struggle with. Indeed, assessing speech-in-noise is more representative of daily life than assessing under optimal conditions (e.g. classroom/playground environments). A number of other studies support the finding that children with language-learning disorders evidence speech perception deficits when a noise mask is present, but not in silence (e.g. Boets et al., 2007a; Boets et al., 2007b; Ziegler et al., 2009). In addition, Ziegler et al. (2011) successfully replicated their 2005 findings, even with a more stringent methodology and set of stimuli (see section 4.1 for a more detailed overview of this work).

Although Ziegler's (2005, 2011) work goes some way in highlighting auditory perception deficits in SLI, it falls somewhat short. In both studies, the stimuli were simple consonantal categories. Sentence stimuli needs to be used if real-world language processing is to be assessed. In addition, we know children with SLI have varied linguistic deficits, especially in inflectional morphology. It needs to be established whether auditory perception deficits can account for a very specific profile of inflectional difficulty. That is, can an auditory processing deficit account for the verb-noun impairment discrepancy that is so evident in children with SLI? The evidence presented in this section cannot answer this question.

1.3.5.2.4 Phonological memory. Another theory of SLI suggests that these children have deficits in phonological memory, which impacts upon their language and grammar development . This theory is largely motivated by the work of Gathercole and Baddeley (1990). In this study, children with SLI were compared to age- and language-matched controls on various language outcome measures. It was found that although children with SLI performed as well as controls in speech discrimination tests and articulation rate, they performed significantly worse than their age-matched peers on a nonword repetition (NWR) test. NWR tests are thought to index phonological working memory (Gathercole & Baddeley, 1990) and as such, it was concluded that the language deficits seen in SLI may be the result of a deficit in this domain. That is, children with SLI may find it difficult to hold and process phonological forms in a temporary memory storage system.

There appears to be a significant amount of support for this hypothesis. For instance, Service (1992) found that one's ability to learn both native and foreign vocabulary items was significantly correlated to one's phonological working memory capacity. This suggests that general lexical knowledge (an area that children with SLI show deficits in) is related to phonological memory. In addition, there have been consistent replications of a nonword repetition deficit in children with SLI (e.g. Dollaghan and Campbell, 1998; Montgomery, 1995). NWR has also been identified as an excellent behavioural marker of SLI (along with past tense elicitation) (Conti-Ramsden et al., 2001). This is the case even when children appear to have 'resolved' their language difficulties (Bishop, North & Donlan, 1996).

When we look at the wider linguistic problems in SLI (outside of inflectional impairments), it seems to be the case that phonological working memory plays a large role in the difficulties experienced. For instance, children with SLI have difficulty comprehending and using complex sentence structures, such as passive constructions (*the ball was kicked by the boy*) and semantically-reversible sentences (*the girl is kissed by the boy*). These aspects of language place great demand on phonological memory (Gathercole & Baddeley, 1993), and so it does seem plausible that a phonological memory deficit is central to the language difficulties experienced in SLI. This is further supported by Montgomery (1995) who presented a sentence comprehension task to children with SLI and language-matched controls. The length of the sentences was manipulated such that they were either short or long (by including redundant information, often adjectives). It was found that children with SLI performed worse than language-matched controls only on the long sentences, and that this long-sentence performance was significantly correlated to NWR ability. Montgomery's (1995) research therefore not only shows that children with SLI may have a phonological working memory deficit, but that it may mediate language deficits in the disorder.

Despite the wealth of literature appearing to demonstrate that a phonological working memory deficit in SLI may be central to the difficulties experienced, there is some evidence that muddies the picture. Snowling (2006) for example found evidence for dissociations between NWR and vocabulary knowledge in language-impaired samples. In addition, there is a significant degree of heterogeneity with regards to phonological memory deficits in SLI, and there are a large proportion of children with SLI who show no NWR impairment (Catts et al., 2005). In addition, Montgomery (2000) found that phonological memory did not correlate with word monitoring task performance in SLI, language-matched or age-matched control groups.

If phonological working memory deficits are central to the language difficulties experienced by some children with SLI, the questions stand of how exactly is this manifested in SLI, and how do these deficits explain the inflectional deficits evident in the disorder. Montgomery (1995) noted that although children with SLI were worse than language-matched controls on a NWR task, they demonstrated the same effects as controls with regards to nonword phonological similarity. That is, lists of phonologically-similar nonwords were recalled less accurately than lists of nonwords that were phonologically-dissimilar. Montgomery (1995) suggested that, based on these findings, children with SLI may have difficulties storing and maintaining phonological information, rather than encoding it. However, Montgomery's (1995) SLI sample demonstrated worse phonological discrimination skills than their language-matched counterparts, which possibly suggests some perceptual deficit. This is supported by the results of Steenbrugge and Chiveralls (1994), which showed children with SLI to have worse real-word and nonword phonological discrimination skills, as compared to controls. Consequently, the NWR deficits that are so prevalent in SLI may be the result of a perceptual discrimination weakness, which results in poor phonological representations, rather than a phonological memory deficit.

In sum it appears that the evidence is somewhat contradictory. Whilst there is a wealth of evidence suggesting that children with SLI have deficits in phonological working memory, and that these are central to the language difficulties experienced, there is counter-evidence that proposes otherwise. It is widely accepted that children with SLI form an extremely heterogeneous sample, and it may be the case that phonological working memory deficits are only evident in a subgroup of children with the disorder. Nevertheless, phonological working memory deficits are likely to be evident in many children with SLI. Exactly how (and if) this affects language processing is still unclear however, and more work is warranted.

1.3.6 Simulation of language impairment. A relatively novel and interesting paradigm to adopt when testing theory and hypotheses is that of simulation. Consider that the inflectional difficulties in SLI may be the result of a speed of processing deficit. Traditionally, one might test this by measuring the inflectional awareness and speed of processing skills in a sample of children with SLI. However, one could also test this prediction using a simulation study: Typically-developing children could perform tests of inflectional processing when the stimuli were speeded, and thus placing 'stress' or 'demand' on the speed of processing . If these children, whose inflectional skills were usually age-appropriate, began to show SLI-like deficits (e.g. impairments in verb morphology but not nouns), further support for the hypothesis would be gained. This simulation paradigm has yielded some very interesting results in the literature.

Kilborn (1991) was one of the first researchers to explore this simulation paradigm, and investigated the effects of stressing the auditory system on grammatical processing in adults. Kilborn compared sentence comprehension in typically-developing English and German adults, when the sentences were presented in optimum and noise-masked conditions. In the optimum (no noise) condition, the English participants made use of word order to perform the task, whereas the German speakers made use of morphological cues. The performance of the English speaking participants was not affected by the noise mask; however the German speakers began to struggle, and shifted their strategy from using morphological information to using word order cues. This suggests that a general cognitive stressor can have a very selective effect on certain aspects of grammar.

In addition to noise masking, increasing cognitive load during sentence processing has been shown to induce a specific Broca's aphasia-like profile in typically-developing adults. Blackwell and Bates (1995) asked adults to perform a grammaticality judgement task whilst simultaneously remembering a string of digits. The length of the digit string was manipulated to increase cognitive load. It was found that cognitive load (number of digits to remember) resulted in a specific profile of grammatical impairment that was akin to that of Broca's Aphasia. That is, agreement errors (*she are reading a book*) were common, and errors of omission (*she reading a* book) and transposition (*she reading a book* is) were not. This again supports the idea that a general cognitive impairment (in this case, working memory) can result in a specific profile of grammatical difficulty.

Miyake, Carpenter and Just (1994) also investigated the effects of a memory load on grammatical processing. Here, participants were assigned to one of three groups, based on their working memory (reading span) capacity: High, medium and low. Participants then were asked to perform two Rapid Serial Visual Presentation sentence comprehension tasks, presented at slow and fast rates (120ms/word versus 200ms/word). Results showed a specific linguistic deficit that mirrors what is seen in Broca's Aphasia when the sentences were presented at a fast rate. In addition, there was an effect of working memory capacity, such that those with the lowest capacities were more impaired by the speeded stimuli than those with a high working memory capacity.

Interestingly, a digit-load cognitive stress condition did not yield significant effects upon language processing in Miyake et al. (1994). This is at odds with the work by Blackwell and Bates (1995), who found that digit-load did significantly impair agreement errors during a grammaticality judgement task. However, as Hayiou-Thomas (2002) highlights, Miyake et al. (1994) used a digit *recognition* task for their stressor, whereas Blackwell and Bates (1995) used a digit- *recall* task, which is more cognitively-demanding (and thus participants were more susceptible to error). In addition, Miyake et al. (1994) mainly looked for errors in word-order, which is a more salient grammatical feature in the English language than agreement, as per Blackwell and Bates (1995). However, Hayiou-Thomas (2002) argues that grammaticality judgement tasks (as used in Blackwell and Bates, 1995) are less challenging than Rapid Serial Visual Presentation sentence comprehension tasks (as used in Miyake et al., 1994), and so even the 'weaker' stressor of digit recognition used in Miyake et al. (1994) should have affected participants' performance.

Finally, Dick et al. (2001) has also demonstrated that general cognitive stressors can induce specific grammatical deficits in typically-developing adults performing a sentence comprehension task. The researchers used a variety of stressors, including a pink stationary noise mask (50% signal to noise ratio), low-pass filter (at 600Hz to degrade the auditory quality) and speech rate compression (to 50% of the original rate). It was found that the noise mask, filter and speech rate compression all induced Broca's Aphasia-like grammatical (sentence comprehension) impairments in the typically-developing participants. Specifically, passive constructions (*the food was eaten by the children*) were associated with more errors than active constructions (*the children ate the food*).

Collectively, the studies presented so far in this section support the view that a specific grammatical profile of impairment may be attributed to a general processing mechanism, rather than a specific linguistic or grammatical system.

As previously detailed, there is a body of literature that simulates Broca's aphasia-like grammatical profiles in typically-developing adults. Hayiou-Thomas, Bishop and Plunkett (2004) were the first to extend this simulation paradigm to children and to a developmental language disorder: SLI. Hayiou-Thomas et al. (2004) successfully induced SLI-like grammatical impairments in typically-developing 6 year olds. The study used a grammaticality judgement task and manipulated the stimulus presentation by way of length (short versus long) and speed (normal versus fast – 50% compression). Such manipulations allowed the authors to explicitly test two competing accounts of the inflectional difficulties seen in SLI: the speed manipulation tested the speed of information processing hypothesis (by simulating a reduced speed of processing in the typically-developing children) and length tested the phonological working memory hypothesis. It was found that both speed and length manipulations resulted in grammaticality judgement task impairment that echoed what is seen in SLI. That is, there was relatively good performance on the regular plural and poor performance on verb inflections, with the regular past tense being more affected than the third-person singular. Speeding the sentences had a more detrimental effect than lengthening them, lending more support to the speed of information processing hypothesis than the verbal short term memory account.

Witherstone (2010) replicated and extended the work of Hayiou-Thomas et al. (2004). In this study, typically-developing 5-7year old children completed measures of inflectional awareness under two types of cognitive stress: working memory (sentences were lengthened by adding 50% more words) and speed of processing (sentences were speeded by 50%). Inflectional awareness was measured by two tasks: a grammaticality judgement task (like in Hayiou-Thomas et al., 2004) and a word monitoring task, so that on-line and off-line performance could be compared. The grammaticality judgement results replicated those of Hayiou-Thomas et al. (2004). That is, both stressors impaired inflectional sensitivity, but speeding sentences by 50% led to a much clearer SLI-like profile of impairment, in that verb morphology was impaired and noun morphology was spared. Interestingly, the word monitoring task data did not find an effect of length, and the speed stressor led to floor effects. Witherstone (2010) concluded that the level of compression (50%) was manageable for the children in the grammaticality judgement task because this is not a time-dependent activity. That is, children can take as much time as they need to answer the question of whether the sentence they had just heard was grammatical or not. However, the word monitoring task is highly time-dependent and centres around speed of response, and so speeding sentences by 50% was simply too much for these children.

Collectively, the studies presented here show that it is possible to simulate a specific profile of language impairment by increasing (or stressing) general, non-linguistic cognitive demands. This literature therefore gives weight to the hypothesis that SLI may be the result of a general cognitive deficit, as opposed to a specific linguistic one.

Simulation paradigms are a relatively novel and interesting way to test hypotheses. They allow for tight controls, given the experimental nature, and provide large sample sizes as participants are typically-developing. This is in contrast to studies looking directly at the clinical population under investigation (SLI in this case), where participant numbers are very low and attrition rates are often high. Simulation studies also give more insight into causal relationships between two factors; in this case, cognitive domains and language skills. In view of all of these points, this thesis adopted a simulation approach for many of its experiments.

1.4 Summary

Children with SLI experience wide-ranging linguistic deficits that cannot be accounted for by impairments in hearing or speech, neurological deficit or general linguistic delay (Leonard, 2014). Such linguistic deficits lie within the domains of grammatical development, vocabulary learning, phonological awareness and sentence comprehension (see Leonard, 2014 for review). Of these deficits, children with SLI appear to have the most difficulty with grammar, with inflectional morphology posing the most trouble (Bishop, 1997). Within the domain of inflectional morphology, children with SLI often experience a gradient of difficulty, such that certain inflections are more troublesome to master than others. Specifically, the regular past tense seems to be the most impaired (e.g. Leonard et al., 1992; Marchman & Ellis Weismer, 1994; Rice & Wexler, 1996; Rice, Wexler & Cleave, 1995), followed by the third person singular (e.g. Bishop, 1994; Leonard et al., 1992; Rice & Wexler, 1996). The regular plural inflection may be impaired to a small degree (e.g. Rice & Oetting, 1993), whilst the progressive inflection seems to be unimpaired in SLI (e.g. Leonard, 2014; Marshall, 2006; Rice & Wexler, 1996; Roberts, Rescorla & Borneman, 1994). This gradient of difficulty largely mirrors the normal order of inflectional acquisition in typically-developing children.

Despite traditionally being regarded as a *specific* linguistic disorder, there appears to be a body of evidence that suggests the difficulties in SLI extend beyond the linguistic domain. For example, research has shown deficits in basic reaction time (e.g. Kail, 1994), mental rotation (Johnston & Ellis Weismer, 1983), picture naming (e.g. Anderson, 1965), word monitoring (e.g. Montgomery & Leonard, 2006), peg-moving (Bishop, 1990) and grammaticality judgements (Wulfeck and Bates, 1995), to name but a few.

There are numerous theories posed that attempt to explain the inflectional difficulties children with SLI experience. These theories often fall into one of two categories: linguistic or cognitive. This thesis will focus on the latter, which include (but is not limited to) speed of information processing, auditory processing, and phonological working memory approaches. A simulation paradigm will be used to explicitly and experimentally test these theories, in view of the merits outlined prior. Broadly speaking, the experiments in this thesis will attempt to induce the specific hierarchy of inflectional difficulty see in SLI in typically-developing children by stressing various cognitive systems. By doing this, it is hoped that further insights into the aetiology of inflectional difficulties in SLI will be gained.

Chapter 2. General Methodology

This thesis consists of four interrelated studies. Experiments 1, 2 and 3 attempted to simulate SLI-like grammatical impairments in typically-developing children by increasing general cognitive load during sentence processing. Experiment 4 attempted to alleviate the grammatical difficulties in children with SLI by reducing the cognitive load during sentence processing. All four experiments measured grammatical (inflectional) awareness using the same task – a Word Monitoring Task. Given that all studies within this thesis used the same experimental paradigm, this chapter will cover general methodology so as to avoid repetition across the experimental chapters. Each experimental chapter will continue to have its own methodology section, which outlines other important information such as the participant details, specific design (within/between groups etc) and any alterations to the basic paradigm.

2.1. The Experimental Paradigm: The Word Monitoring Task

As discussed in section 1.2, there are two directions one can take when designing tasks to assess inflectional morphology skills: offline and online. Offline tasks are those that measure awareness after sentence processing has taken place. Online tasks on the other hand measure in real-time, and as such are a more direct and implicit measure of inflectional awareness.

The (offline) grammaticality judgement task is the most widely-used in the literature, and certainly has some strengths. The grammaticality judgement task is very much a binary measure, in that children either rate an auditory-presented sentence as grammatical or not. This has the advantage of being suitable for very young children, given the simplicity of the task (e.g. Rice et al., 1999 showed it to be effective for children as young as 4;1years). In addition, the task is free of problems surrounding production and pronunciation in the participants. However, one is not able to compare the relative ungrammaticality of two ungrammatical constructions (Ambridge & Lieven, 2011), or to assess the reason for the judgement in this type of task. Additionally, the grammaticality judgement task lacks ecological validity. Language is a rapidly-evolving medium that requires real-time processing. It is rare for real-world language to be processed in an off-line manner, such as in the grammaticality judgement task. Finally, the grammaticality judgement task places great demand on both working memory and metalinguistic skills. This may confound the results in any experiment, but certainly would in the experiments contained within this thesis: Given that cognitive load is manipulated as an independent variable in all experiments, the level of cognitive demand required to measure the dependent variable (inflectional awareness) needs to be minimal.

In view of the weaknesses of the grammaticality judgement task, this thesis adopted an online Word Monitoring Task throughout its experiments. This has been described in some detail in section 1.2, but as a reminder, this task is an effective real-time measure of both general language processing and specific inflectional processing (Montgomery & Leonard, 2006). In the task, a participant hears a target word, and then is required to press a response button as soon as they hear the given target embedded within a sentence. To assess inflectional processing, the sentences are manipulated for grammaticality, such that the target word is immediately preceded by a critical word that is either appropriately inflected or inappropriately uninflected (i.e. a bare stem where there should be an inflected form). A typical pattern of results shows slower reaction times to the target word when the critical word is ungrammatical, as compared to grammatical. In addition, reaction times are generally slower to targets following a verb item, as compared to a noun item (e.g. Montgomery & Leonard, 1998). For instance, reaction times to the target 'football' are typically faster in the sentence "last week the boy played football with his friends", as compared to the sentence "last week the boy play football with his friends". This difference in reaction times indicates processing of the inflections; if there is no significant reaction time difference between grammatical and ungrammatical sentences, a lack of inflectional processing is implied (Montgomery & Leonard, 2006). Experimental work has shown that the word monitoring task is effective in measuring general lexical processing (Montgomery, Scudder, & Moore, 2008; Montgomery, 2000, 2002) and in assessing morpheme awareness in both children with SLI and those that are typically-developing (Montgomery & Leonard, 2006).

The word monitoring task does not require any explicit judgement from the participant as to the grammaticality of the sentence they have just heard; it is very much an implicit measure. It therefore places less demand on working memory and metalinguistic skills, as compared to grammaticality judgement tasks (Miller, Leonard, & Finneran, 2008). The word monitoring task also allows investigation into the unconscious representations and processes involved in sentence processing (Tyler, 1992); something that more traditional off-line tasks fail to do. Unlike the grammaticality judgement task, one can gauge some idea as to relative ungrammaticality with the word monitoring task, by comparing reaction times across sentences. The word monitoring task is also higher in ecological validity than the grammaticality judgement task, as it requires real-time language processing, just as the real-world does. However, it must be remembered that the word monitoring task is slightly more complex than the grammaticality judgement task, and so children may have to be older in studies using this methodology, and that there is more room for error or floor effects.

2.1.1. Test-retest reliability of the Word Monitoring Task. Although the word monitoring task has been used relatively frequently in the literature, its reliability has not yet been assessed. Twenty children from the baseline condition in Experiment 2 were re-tested three months after the first session, in an attempt to gauge the test-retest reliability of the task. Scores were very reassuring: the two time points correlated with each other strongly at .759. In addition to test-retest reliability, the internal consistency (Chronbach's alpha) was high at α=.841. Combined, both of these analyses provide reassuring evidence that performance on the word monitoring task is consistent within the experiment, and is stable over time.

2.2. The Experimental Stimuli

Each experiment in this thesis had its own stimulus set, which assessed awareness of various English inflections. Table 2 details which inflections were studied in each of the four experiments, with a tick indicating that the inflection was assessed. Awareness of each inflection was assessed by creating a number of sentences for the word monitoring task in which the critical word either contained (grammatical construction) or omitted (ungrammatical construction) the specific morphological item. There were 10 items per inflection in experiment 1 and 2, and 8 items per inflection in experiments 3 and 4. Appendix A details the stimuli item sets for each of the four experiments.

Table 2. Inflections assessed in each of the four experiments of this thesis.

Experiment	**Plural ~s**	**Regular Past Tense ~ed**	**Third Person Progressive ~s**	**Present Progressive ~ing**
1	✓	✓	✓	✓
2	✓		✓	
3	✓	✓	✓	
4	✓	✓	✓	

All of the baseline stimuli that comprised the Word Monitoring Task sentences were in the active voice and of simple construction, generally assuming subject-verb-object order. Tense was indicated by the sentence beginning with either *yesterday, last week, every day, every week, today, this week*; the use of tense markers was counterbalanced throughout. Plurality was marked by a single digit preceding the noun (e.g. *the man saw **two** birds flying in the sky*). All critical verbs and nouns that were manipulated for grammaticality were monosyllabic, and it was ensured that in each sentence no word prior to the target sounded similar to the target itself to limit the likelihood of false alarm responses.

All baseline stimuli (target words and associated sentences) for each experiment were recorded by the experimenter (native English speaker) in a sound-proof room using a Sony ICD-UX71 digital voice recorder at a sample rate of 44100Hz. Sentences were spoken at a steady rate. Audacity (version 1.3.13, available at www.audacity.sourceforge.net) and PRAAT (Boersma, 2001) were used for stimulus editing. All sentences were recorded at the same volume, and any noise was removed from the sound files. Each sound file began with a 1.5second silence, upon which the target word was presented. Another 1.5second silence followed, before the sentence was presented that contained the previously-presented target item. Children were always given two practice trials before participating in the experiments.

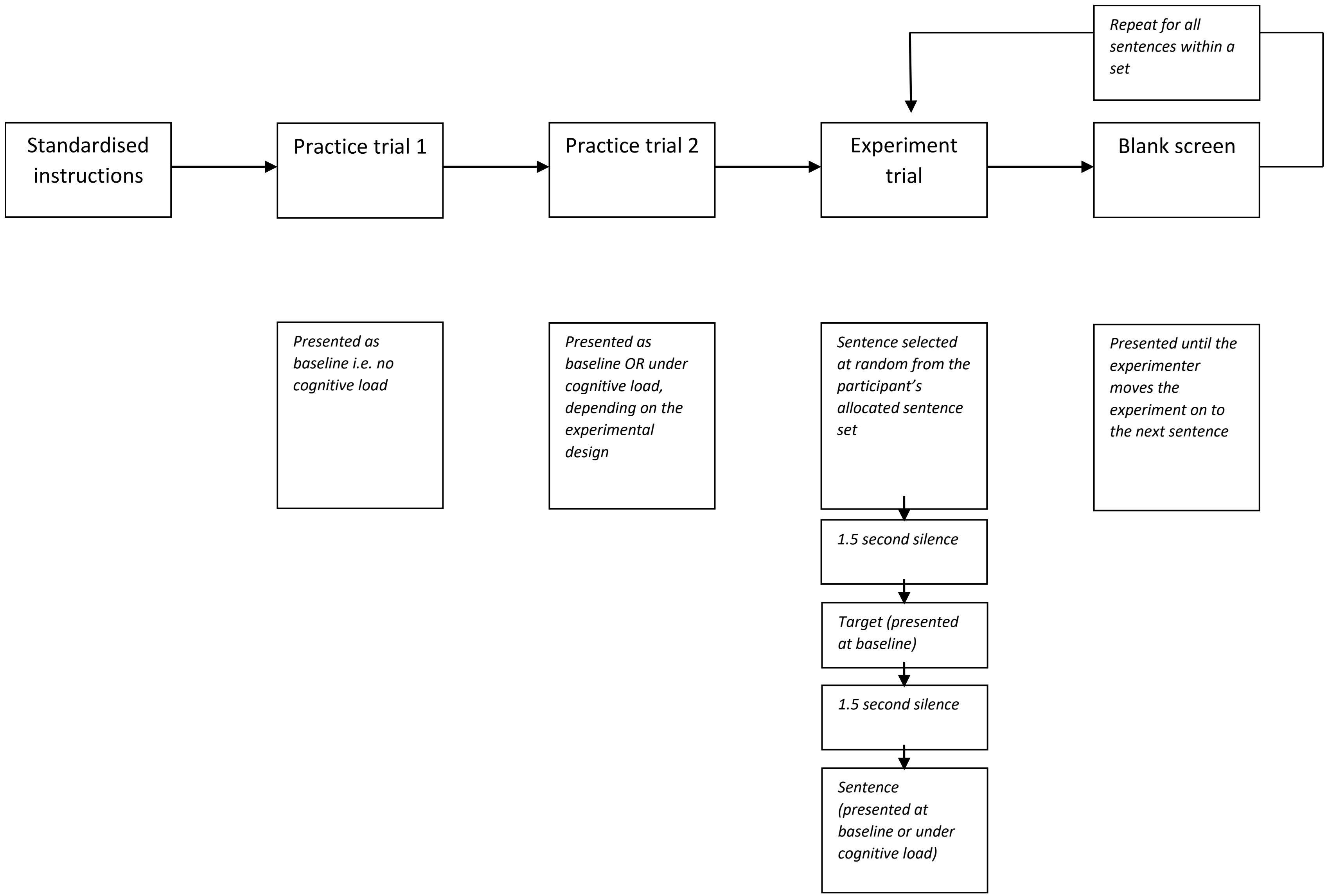
2.2.1. Presentation of experimental stimuli. E-Prime (version 1.1; Schneider, Eschman & Zuccolotto, 2002a; 2002b) was used to present the stimuli to the participants in all of the experiments in this thesis. Separate E-Prime files were created for each sentence set within each experiment, and the order of sentence presentation within each set was randomised for each child. As reaction times are central to the word monitoring task paradigm, E-Prime was coded to record the time taken to press the spacebar for each sentence presented to a child, so that 'target word reaction times' could be computed for analysis.

Figure 3 demonstrates how the stimuli were presented to the children in the basic paradigm (variations from this will be described in detail in each experimental chapter). All children in all experiments received the same standardised instructions before the Word Monitoring Task began. They are as follows:

> *You will shortly hear a special word. Then you will hear a sentence that uses that special word. As soon as you hear the special word in the sentence, press the spacebar as fast as you can.*

The experiments were all presented via a Toshiba Satellite Pro laptop computer and Sennheiser HD201 headphones.

Figure 3. The word monitoring task procedure



2.3. Language and Cognitive Assessment

Each of the four experiments within this thesis involved some level of standardised language and non-verbal IQ screening for the participants, to examine whether they would be identified as ‘typically-developing’ (for experiments 1, 2 and 3) or as having SLI (for experiment 4). A variety of other standardised tests were also used, depending on the rationale, predictions and arguments developed for each individual experiment. Each subsequent experimental chapter will discuss this in more detail along with the reason(s) for the test battery selection, but Table 3 provides an overview of what constructs were examined in each of the four experiments (a tick indicates that the construct was measured). The remainder of this chapter covers the test battery for each construct in more detail.

Table 3. Constructs assessed in each of the four experiments of this thesis.

Exp. #	**Cognitive construct**					
	Vocab.	Grammar	Nonverbal IQ	Speed of Processing	Attention	Short-term phonological memory
1	✓	✓	✓			
2	✓	✓	✓	✓	✓	
3	✓	✓	✓		✓	
4	✓	✓	✓		✓	✓

2.3.1. Vocabulary. Various subtests were used from the Clinical Evaluation of Language Fundamentals, fourth UK edition (CELF-IV; Semel, Wiig & Secord, 2006) throughout the experiments in this thesis to measure different aspects of vocabulary. The CELF-IV is a large standardised test that is made up of subtests, designed to measure various different language skills in children aged 5-9 years. One can choose to administer the whole CELF-IV measure, or individual subtests.

The CELF-IV Concepts and Following Directions subtest assesses syntactic and metalinguistic skills, and was used in experiment 1. In this test, children are presented with a row of objects and are asked to point to a selection of objects in a specific order. The complexity of the oral instructions increases throughout the test. For example, children are asked to "point to the red apple and then the blue shoe" in the simple instances. A more complex instance would see children being instructed to "point to the green ball that is next to the red flower, before you point to the yellow book".

The CELF-IV Recalling Sentences subtest measures syntax and metalinguistic skills, as well as language memory. Children simply listen to a sentence, and then repeat it verbatim, without delay. Sentences increase in length and syntactic complexity. This test featured in the test battery of experiments 1 and 4 of this thesis.

The CELF-IV Formulated Sentences subtest assesses syntactic and semantic skills in children. In this test, children are required to generate a sentence to describe a picture using a target word or phrase. Targets and pictures increase in complexity throughout the test. This test only featured in experiment 1 of this thesis.

The CELF-IV Expressive Vocabulary subtest asks children to simply name pictures of people, objects and actions which increase in difficulty. The task is a measure of expressive vocabulary, and was used in experiments 1, 3 and 4.

As well as the CELF-IV, this thesis made use of the BPVS-III to measure receptive vocabulary (experiments 2 and 4). This is a widely-used receptive vocabulary test that requires children to select which picture (from an array of four) best matches a given word. The words become more complex as the test progresses. Words are arranged into blocks of 12, and children must score at least 4 words correctly within a set to move onto the next one. The BPVS-III is regarded as an excellent measure of receptive language ability, and as a good indication of the presence or absence of a language disorder.

2.3.2. Grammar. The Word Structures subtest of the CELF-IV was the most commonly-used measure of expressive grammatical skills throughout the experiments of this thesis (experiments 1, 3 and 4 used this subtest). In this subtest, morphological ability is assessed by asking children to finish sentences using pictures that are designed to illicit various morphemes. For instance, a child would see two pictures – one of a man climbing a ladder, and one of just the ladder. The instructor would say "here is a man climbing a ladder" (pointing to the first picture). The instructor would then point to the second picture and say "here is the ladder that the man ________", in the hope of eliciting the past tense verb 'climbed'.

The Test of Reception of Grammar, 2nd edition (TROG-2) was used in experiment 2 as a grammatical measure. The TROG-2 is similar in structure to the BPVS, in that children are required to select one of four pictures that best match a sentence spoken by the tester. The test measures understanding of various English grammatical constructs of increasing complexity: For example, a simple item would ask a child to point to the picture that matches *"the boy is running"*; a more complex item would ask a child to point to the picture that represents *"the cup is inside the box"*. As with the BPVS, it is widely regarded as a strong indicator of the presence or absence of a language disorder.

2.3.3. Nonverbal Intelligence. The most commonly-used measure of nonverbal intelligence was the Weshsler Intelligence Scale for Children, fourth edition (WISC-IV) Block Design subtest. This subtest measures a child's 'fluid intelligence', problem-solving and manipulative abilities, and experiments 2, 3 and 4 of this thesis made use of Block Design. It is a timed test, and involves children arranging a selection of red and white blocks to match patterns shown on test cards. The patterns get more complex as children move through the items, and testing is stopped after three consecutive failed items.

Experiment 1 used the Nonverbal Reasoning cluster score from the British Ability Scales, second edition (BAS II; Elliott, 1996) to measure nonverbal ability. The Nonverbal Reasoning cluster score is composed of Matrices and Quantitative Reasoning subtests that both measure inductive reasoning skills. In Matrices, a child is shown a pattern on a grid with a missing 'square'. They are given four options and are required to select which of the four represents the missing square. In the Quantitative Reasoning subtest, children are required to complete the blank side of domino-type pictures – they need to figure out what they need to put on the right side depending on the pattern on the left.

2.3.4. Speed of Processing. Experiment 2 was the only experiment to use a nonverbal speed of processing measure. This was the WISC-IV symbol search, which is a measure of processing speed, concentration and cognitive flexibility. In this test, children are required to visually scan a search group for a target symbol, which may or may not be present. The test is timed.

2.3.5. Attention. Experiment 2 measured attention using two different tests from The Test of Everyday Attention for Children (TEA-Ch). The Map Mission subtest measures selective/focussed attention, and gives children one minute to circle as many target symbols as they can on a map. The Walk-Don't Walk subtest measures sustained attention and response inhibition. It is a pencil-and-paper task where children take 'steps' along a path each time they hear a 'go' beep played on a tape. The children must stop (inhibit their response) taking steps when a 'stop' beep is played. Children are given practice with the 'go' and 'stop' sounds before testing). The beeps get faster as the test progresses.

2.3.5.1. The Flanker Task. Experiments 3 and 4 used the Flanker Task as a measure of attention. This task is a popular measure of focussed attention, whereby participants are required to attend to some information and ignore other distracting information. In a traditional Flanker Task, participants see a row of items (letters, for example). The central item is the target, and the surrounding items are the *flankers* – the distracters – and can be either congruent or incongruent to the target (e.g. Eriksen & Eriksen, 1974). Participants are required to make a binary directional key-press response depending on the target in order to classify it, and must ignore the flanker items.

For instance, in the original test (Eriksen & Eriksen, 1974), participants were required to press the right arrow key if the target (central item) was a letter H or K, and the left arrow key if the target was a letter S or C. An example of a congruent stimulus would be HHHKHHH where both the target and flanker are associated with the same directional response. An incongruent trial would be, for example, HHHSHHH, where the target and flankers are associated with different directional responses. Typically, reaction times and accuracy to the target item are affected by the congruency of the flanker items, with faster and increased accuracy responses in the incongruent trials (Eriksen & Eriksen, 1974).

The particular Flanker Task used in this experiment was one based on red and green dots, as coloured dots were shown to be the most effective Flanker task to measure attention in young children (McDermott, Pérez-Edgar & Fox, 2007). Participants saw a row of five dots on the screen, and were required to press a button on a keypad depending on the colour of the central dot. If the central dot was red, participants pressed the red button. If the central dot was green, participants pressed the green button. The 'flanking' (surrounding) dots varied in colour depending on the congruency of the trial: Incongruent trials had flanking dots that were the alternative colour to the central dot, whereas congruent trials had dots that were the same colour as the central dot. Figure 4 shows this task for clarity. Participants experienced 28 trials, half of which were congruent and half were incongruent.

The reaction time difference between congruent and incongruent trials represents the 'conflict effect', and is an indication of a child's ability to focus their attention and ignore distracting information. With this in mind, it appears that the Flanker Task seems to draw some parallels to the Word Monitoring Task. Whilst children are asked to focus on the central dot and ignore surrounding information in the Flanker Task, they are asked to focus on the target word and not respond to the surrounding words in the sentence in the Word Monitoring Task.

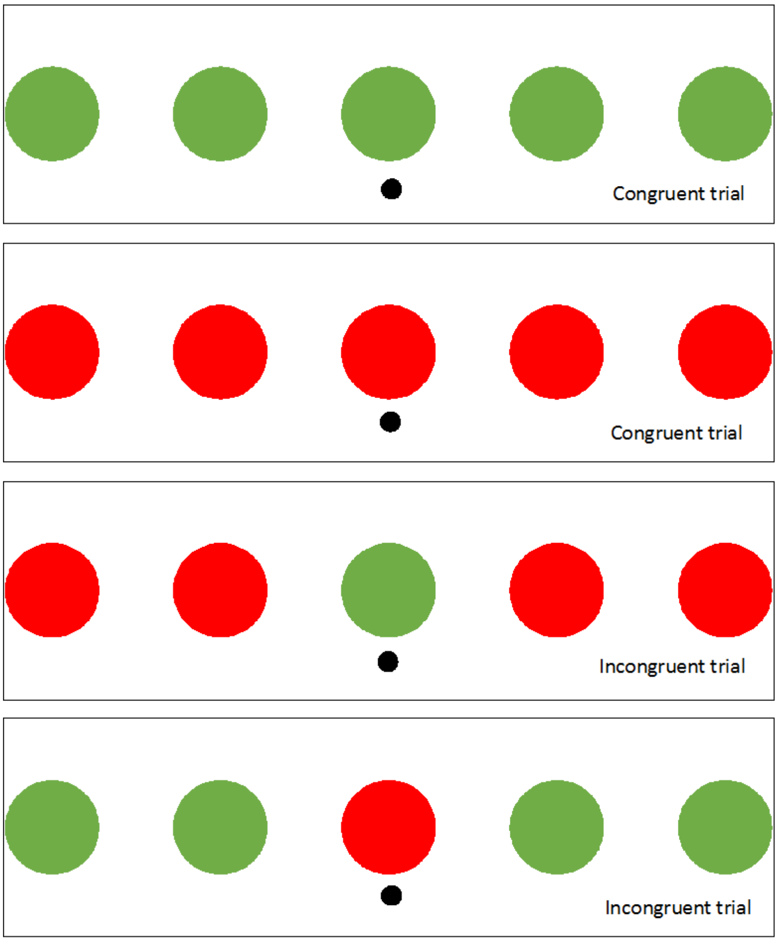


Figure 4. Flanker Task example, as used in experiments 3 and 4 of this thesis.

2.3.6. Phonological Short Term Memory. The only experiment to include a measure of Short Term Phonological Memory was experiment 4, which included the Children's Test of Nonword Repetition (CNRep, Gathercole, Willis, Baddeley & Emslie, 1994). The CNRep requires participants to repeat, verbatim, nonwords of varying length and phonological complexity. This test is a measure of phonological short term memory, and is widely regarded as an excellent measure of the presence of a language disorder (Gathercole et al., 1994).

2.4. Other assessment

In addition to collecting data on participants' language and cognitive aptitude, all of the experiments in this thesis recorded age and sex, as well as whether the children had any history hearing loss or developmental disorder.

Given that the word monitoring task is a measure of speed, all experiments within this thesis also involved a basic auditory reaction time test to ensure that any differences in baseline auditory response speed between participants could be controlled. In this auditory reaction time task, participants were required to press the spacebar on the laptop as soon as they heard a 'beep'. Eighteen 'beeps' were heard in total, each lasting .5 seconds. The 'beeps' each followed a period of silence that varied randomly between 300ms and 900ms. The mean reaction time across all 18 trials was calculated for each child to establish their 'baseline auditory reaction time'.

2.5. Ethical considerations

All experiments in this thesis were approved by the University of York's Ethics Committee.

For all experiments, fully informed parental and school consent was gained for each child before any testing began. Before the experiment started, children were told what the experiment would involve, and were asked if they would like to take part. The children were told that they could go back to their classroom at any point, without consequence. Parents and schools were also free to withdraw any child at any point. After the children had taken part, they were given a letter to take home to their parents. This letter confirmed that their child had participated in the experiment, and contained the experimenter's contact details and their child's unique identification number so they could discuss matters or withdraw their child's data at a later date. Schools were also given a debrief letter after all children had participated, as well as the only sheet which had each child's name and their unique identification number (the experimenter only used identification numbers when handling data). The experimenter did not have a record of names; just identification numbers, gender and dates of birth were used when handling data. This ensured complete anonymity of participants.

Chapter 3. Experiment 1: Speed of Processing

3.1. Introduction

There is much literature to support the idea that a deficit in auditory processing skills may mediate the language difficulties seen in the disorder. Early hypotheses suggested that a deficit in processing rapidly-presented stimuli was central to the language difficulties experienced by children with SLI (e.g. Tallal & Piercy, 1973; see section 1.3.5.2.3 for a detailed overview). However, support for this account is sparse, and there is much literature that contradicts the idea that SLI is mediated by a rapid temporal processing deficit (see section 1.3.5.2.3). There is strong evidence however that suggests the deficit in SLI is more fundamental, relating to general speed of processing, rather than being exclusively tied to rapidly-presented information.

In this generalised Speed of Processing hypothesis, it is suggested that the speed with which a child can process information mediates their language ability, and that a deficit in speed of processing can result in language difficulty (e.g. Miller et al., 2001). As discussed in section 1.3.5.2.1, it has been argued that children with SLI may be slower (by a proportionate amount) to process information than both chronological age matched and language matched children (e.g. Kail, 1994; Miller et al., 2001; Wulfeck & Bates, 1995). This difficulty is believed to extend to language processing and to have a causal role in SLI. That is, children with SLI may struggle to process the language that they hear in a time-effective manner, resulting in impaired linguistic and grammatical representations, relative to age and language matched controls (e.g. Stark & Montgomery, 1995; Montgomery & Leonard, 2006).

If the grammatical difficulties of children with SLI do indeed have associations with problems processing normal-rate language, it stands to reason that altering stimuli input rate should, in turn, affect their language processing ability. Initial work by Stark and Montgomery (1995) appears to refute this line of reasoning however. They conducted the word monitoring task using sentences presented at normal and 25% faster rates to children with SLI and controls. It was found that in the normal-rate condition, children with SLI responded slower and less accurately (i.e. they were more likely to respond before the target word had appeared, or were more likely to not respond at all) to the target word than their typically-developing peers. The faster rate of sentence presentation did not change the children with SLI's reaction times or accuracy to the target words. This finding suggests that speed of processing has little bearing on the linguistic performance of children with SLI (as measured by the word monitoring task at least). Interestingly, the results also showed that the reaction times and error rates of the typically-developing children were significantly improved in the fast-rate condition.

Although their work seems to suggest speed of processing has little relationship to online language processing in SLI, Stark and Montgomery included false alarms in the reaction time analyses (responses before the target word appeared), as well as non-responses. This could have led to false fast mean reaction times (Montgomery, 2002). This confound was not present in later work by Montgomery (2005); the findings of which give more promise. This later work successfully demonstrated that when stimuli articulation speed was slowed down, children with SLI performed similar to age-matched controls in an online linguistic task. That is, when children with SLI were given more time to process sentences, their language skills improved and came close to age-appropriate levels.

Montgomery (2005) assessed the word monitoring task performance of children with SLI and age-matched controls when the sentences were at a normal speech rate, 25% slower and 25% faster. In the normal speech rate condition, word monitoring task reaction times were slower for the SLI group than controls, and were less accurate too. The children with SLI significantly benefitted from the slower speech rate (i.e. faster and more accurate reaction times in the word monitoring task) and the typically-developing children were hindered by the slower rate (in terms of both speed and accuracy), presumably because of the increased temporal and attentional demands that come with slower-rate stimuli. As with Stark and

Montgomery (1995), the typically-developing children's reaction times and accuracy were significantly improved in the fast condition, whereas, predictably, the children with SLI were most impaired in this condition. Montgomery (2005) suggested that the increase in reaction times and accuracy for the typically-developing children in the fast-rate condition was because children were forced to increase their attention, and to stay more focussed. In essence, the typically-developing children saw the fast-rate task as a challenge, and they 'stepped-up' to it. Broadly speaking, Montgomery's (2005) research suggests that linguistic processing may indeed be dependent upon speed of processing, and that it possibly plays a causal role in SLI.

Other studies also lend support to the idea that speed of processing may play a causal role in the language skills of both typically-developing children and children with SLI. For example, Ellis Weismer and Hesketh (1996) demonstrated that increasing stimuli auditory input rate can negatively impact upon nonword learning in typically-developing children. In addition, Montgomery (2004) demonstrated that a slower auditory stimuli input rate can enhance off-line sentence comprehension in both typically-developing and language-impaired children. Finally, the findings of Fazio (1998) show how a slower auditory stimuli input rate can enhance serial memory for lexical items in typically-developing children, and that a faster stimuli input rate can impair lexical serial memory in children with SLI. Collectively, these findings suggest that language processing may have some relationship to the generalised speed of information processing cognitive system.

Although the results presented thus far are interesting, there is no known study that relates speed of processing to *grammatical* awareness. For instance, the word monitoring task can be an effective measure of inflectional awareness if you compare the respective reaction times to target words that follow grammatical and ungrammatical critical words. So, if the participant is processing grammaticality, you should see slower reaction times to target words that follow ungrammatical critical words in comparison to target words that follow grammatical critical words. However, Montgomery's work (Stark & Montgomery, 1995; Montgomery, 2005) did not compare the reaction times in grammatical and ungrammatical constructions in their word monitoring tasks; they simply looked at absolute reaction times and assessed general lexical processing. So, whilst it is true that the children in Montgomery's (2005) study (for example) had lexical processing that seemed to be contingent upon the speed of stimuli input, it is not necessarily the case that these children's *grammatical* awareness was related to speed. To determine this, one needs to compare relative grammatical and ungrammatical reaction times, and this was not a feature of Montgomery's work.

In addition to the issue outlined prior, Montgomery (Stark and Montgomery, 1995; Montgomery 2005) did not control for specific inflections in his stimuli. It is well established that children with SLI experience a hierarchy of inflectional difficulty, with verb morphology posing more trouble than noun morphology, and within this the regular past tense being the most problematic (see section 1.3.3 for a review). In addition, research has shown faster reaction times to targets that follow a noun, as compared to targets that follow a verb (e.g. Montgomery & Leonard, 2006). It is therefore important to control for, and be explicit about, the particular inflections manipulated in one's study, especially if that study is focussed on reaction times. A stimuli list containing all noun/plural items would yield very different results in an SLI sample to one containing all verb/past tense items, for instance.

As it has been shown, there is research that demonstrates interesting experimental results with regards to the relationship between speed of processing and language ability. However, there is a significant lack of research that relates speed of processing to on-line *inflectional* processing. This gap in the literature formed the basis of this first thesis experiment.

As discussed in section 1.2, there are two common task types used in the literature to assess inflectional awareness: grammaticality judgement (offline measure) and word monitoring (online measure). Offline measures require post-hoc language processing, and the grammaticality judgement task in particular places great demand on an individual's verbal short term memory system. This is because in a grammaticality judgement task, one is required to process and store the whole sentence before making a judgement as to its grammatical status. Given that this experiment is focussed on the speed of processing, it seemed sensible to avoid the grammaticality judgement task that places stress on another cognitive domain (memory). A method that is low in cognitive load constraints should be used, and the word monitoring task seemed to fit this requirement. The word monitoring task is effective in measuring general lexical processing (Montgomery, 2000; 2002; Montgomery et al., 1990) and in assessing morpheme awareness in both children with SLI and those that are typically-developing (Montgomery & Leonard, 2000).

To broaden the literature and to help investigate a causal link between speed of processing and grammatical deficits in SLI, a simulation paradigm was adopted in the present study. If it can be shown that an SLI-like profile of inflectional impairment can be induced in typically-developing children by stressing their speed of processing ability, it will lend support to the idea that reduced speed of processing may be a causal factor in the grammatical difficulties seen in SLI.

A number of studies have shown that a specific grammatical profile of impairment can be simulated in typically-developing individuals by introducing cognitive stress (see section 1.3.6 for a detailed review). For instance, Kilborn (1991) successfully induced specific morphological deficits in German-speaking typically-developing adults by presenting stimuli in noise-masked (degraded auditory quality) conditions. Blackwell and Bates (1995) were able to simulate Broca's aphasia-like grammatical deficits in typically-developing adults by stressing verbal working memory, and Miyake et al. (1994) showed that selective Rapid Serial Visual Presentation sentence comprehension skills could be impaired in typically-developing adults by speeding stimuli, and thus stressing the speed of information processing system. Finally, Dick et al. (2001) demonstrated that a variety of general cognitive stressors (including pink noise masking at 50% signal-to-noise ratio (average signal-to-noise ratio of -12dB), speed of processing at 50% speed compressed and low-pass filtering) could each independently induce specific grammatical deficits in typically-developing adults performing a sentence comprehension task.

Hayiou-Thomas et al. (2004) were the first to extend this ‘grammatical impairment simulation’ paradigm to children, and successfully simulated an SLI-like pattern of grammatical difficulty in typically-developing children by stressing participant’s speed of processing. Specifically, Hayiou-Thomas et al. (2004) presented typically-developing 6-year-old children with a grammaticality judgement task under normal and 50% time-compressed (fast) stimulus presentation rates. In the fast-rate condition, the typically-developing children displayed SLI-like grammatical errors; that is, there was relatively good performance on plural (noun) inflections, and very poor past tense and third-person singular (verb) scores. No such error profile was evident in the normal-rate condition for the typically-developing sample.

Hayiou-Thomas et al. (2004) were the first to demonstrate that a specific SLI-like pattern of grammatical difficulty can be simulated in typically-developing children, as measured by an off-line grammaticality judgement task. However, simulation of SLI-like inflectional deficits has not been published since, and is yet to be demonstrated in on-line processing.

Witherstone (2010) looked to replicate and extend the work of Hayiou-Thomas et al. (2004). In this study, typically-developing children aged 5-7years were asked to complete grammaticality judgement and word monitoring tasks under normal and fast (50% compressed) rates. The stimuli included past tense, third person singular, plural and progressive inflections. It was found that for the grammaticality judgement task, the typically-developing participants performed at ceiling levels in the baseline, normal-rate condition. When sentences were speeded however, the children demonstrated an SLI-like profile of inflectional difficulty. That is, when children were explicitly asked about the grammaticality of a sentence after they had heard it, their ability to detect ungrammaticality in the regular past tense was the most impaired, followed by the third person singular inflection. The plural and progressive constructions were unaffected by the speed stressor. This replicated the work of Hayiou-Thomas et al. (2004), and gives further support to the idea that the inflectional difficulties experienced by children with SLI may indeed be the result of a deficit in the speed of processing system.

Although the grammaticality judgement results are promising, the pattern is not quite as clear when the word monitoring task data is assessed. When children's grammatical awareness was assessed online in real-time (as opposed to offline in the grammaticality judgement task) to normal-rate sentences, children responded the fastest to targets following regular plural and present progressive constructions. The slowest response times were associated with target words following regular past tense constructions, followed by the third person singular. This mirrors the 'standard' word monitoring task finding (cf. Montgomery & Leonard, 2006). However, when sentences were speeded by 50%, children performed at floor in all four inflections. It was argued that, since the word monitoring task is highly time-dependent (as opposed to the grammaticality judgement task that is not time-dependent) the speed increase was simply too fast for the children.

It is currently unknown whether the cognitive stressor of speed affects inflectional processing in real-time, or whether it is a delayed effect that manifests in off-line tasks, such as the grammaticality judgement task as used by Hayiou-Thomas et al. (2004). Consequently, this study aimed to directly test whether stress on the speed of processing can ‘induce’ online SLI-like inflectional processing deficits in typically-developing children, as measured by an online word monitoring task.

With regards to speed of processing in SLI, there are many hypotheses in the literature as to the specifics of *how* it is affected. One influential hypothesis is Generalised Slowing (e.g. Kail, 1994). Here, it is suggested that children with SLI are slower than their typically-developing peers to process all types of information by a proportionate amount, and that this indirectly results in impaired linguistic and grammatical representations. When reviewing research on generalised slowing in SLI in section 1.3.5.2.1, it was noted that the specific proportion of slowing remains in contention. For instance, Kail's (1994) meta-analysis suggested that children with SLI experience a 'slowing' rate of approximately 33%. However, Windsor and Hwang (1999) noted a slowing rate of approximately 18%, and Miller et al. (2001) concluded that children with SLI experience a 14% reduction in speed of processing. With regards to experiments that manipulate stimulus presentation rate, Montgomery's work (Stark & Montgomery, 1995; 2004; 2005) altered their speech rate by 25%, and Ellis-Weismer and Hesketh (1996) altered their stimulus presentation rate by approximately 35%, in-line with Schmitt and Moore (1989). Because of the wide variation in slowing rates in the literature, this experiment systematically manipulated sentence speed (by increases of 10%, 20% and 30%), with the aim of establishing a 'best-fit' to simulate SLI (50% has been shown to be too fast in Witherstone (2010), and so this experiment only went as fast as 30%). To date, there has not been any research that has systematically manipulated sentence speed in an experimental paradigm.

In summary, this experiment attempted to simulate SLI in typically-developing children by stressing speed of processing. Due to inconsistency within the literature with regards to the exact slowing rate, and a gap in the field, this experiment planned to systematically present sentence stimuli at rates of 10%, 20% and 30% faster than normal, to try and establish a "best fit" of SLI simulation. A word monitoring task was used to measure implicit awareness of inflections, in view of the lack of literature, strengths of this method, and the memory demands in the alternative grammaticality judgement task. A specific profile of inflectional impairment was sought, with the most impairment evident in the regular past tense, followed by the third person singular and then the regular plural inflection, if SLI was to be accurately simulated. The progressive inflection is unimpaired in SLI (Bishop, 1997) and so acted as a control; it should have remained robust in the face of the speed stressor.

There were two hypotheses for this experiment. Firstly, it was predicted that speeding sentence rate would lead to greater accuracy and speed in the word monitoring task, as compared to a normal rate of stimulus presentation (hypothesis one). This prediction is based on the work of Stark and Montgomery (1995) and Montgomery (2005), who found an increase in accuracy and speed in fast-rate sentences for their typically-developing participants, presumably because they increased their attention and focus in the more challenging condition. Given that this study was using typically-developing children whose lexical processing systems are well-established, and that the stimuli were simple in nature, the same findings were expected here.

The second prediction for this experiment surrounded a child's ability to detect ungrammaticality in the stimuli (as evidenced by a significant difference in reaction times between grammatical and ungrammatical constructions). It was expected that a hierarchy of inflectional impairment would be induced as a result of speeded stimulus presentation rate. This hierarchy was expected to have reflected what is seen typically in SLI: the regular past tense to be most impaired followed by the third person singular, and then the regular plural. The progressive remains unimpaired in SLI, and should have therefore remained robust in the face of increased stimulus presentation speed. As there is much inconsistency in the literature, it was open-ended as to what exact compression rate would lead to the most accurate 'simulation', although it seems likely to be either 20% or 30%.

3.2. Method

3.2.1. Participants.

A total of 112 children were recruited from five North Yorkshire primary schools. All participants were native monolingual English speakers and had no history of speech, language, learning or hearing difficulties, as reported by their school teacher. Both school and parental consent was gained for each child prior to any testing.

Children were randomly allocated to one of the four experimental conditions relating to speed of stimulus presentation: Control (0% compression), 10% compression, 20% compression, 30% compression.

3.2.1.1 Initial screening. Each child who had parental consent was initially screened for language, grammar and nonverbal ability to ensure they were typically-developing. Language and grammar was assessed using the Core Language Score from the Clinical Evaluation of Language Fundamentals, fourth UK edition (CELF-IV; Semel, Wiig & Secord, 2006), which is a composite factor comprised of four subtests: concepts and following directions (assesses syntactic and metalinguistic skills); word structure (measuring morphological ability); recalling sentences (taps syntax and metalinguistics); formulated sentences (assesses syntax and semantics). Note that each child displayed near-ceiling performance on the word structure subtest items that assess the four inflections under investigation in this report. Nonverbal ability was measured using the Nonverbal Reasoning cluster score from the British Ability Scales, second edition (BAS II; Elliott, 1996). Further information about the initial screening is provided in chapter 2.

Three children were excluded from the study as they failed to achieve age-appropriate scores on either the Core Language score of the CELF-IV or the Nonverbal Reasoning cluster of the BAS II. In addition, a further nine children were removed from the analyses as they did not complete all elements of the experiment. As such, data presented from this point forward are based upon a total N of 100 children. Of these 100 children, 55% were female. There was a mean age of 6;60 (years; months) (SD 7.62 months).

Table 4 details the descriptive statistics for each speed group. There were no significant differences in age ($p=.803$), gender ($p=.954$), core language score ($p=.102$) or nonverbal ability ($p=.205$) between the four groups.

Speeded condition	N of participants	Mean age (months)	% Females	Core Language Standard Score	Nonverbal Reasoning Cluster sum of T scores
0%	26	76	56	99	97
10%	26	79	57	98	101
20%	21	77	54	102	98
30%	27	80	53	97	94

Table 4: Descriptive statistics for each of the four groups (experiment 1).

3.2.2. Experimental stimuli. There were four inflections under investigation in this experiment: the regular past tense, third person singular, regular plural and the progressive. Three sentence sets were created that each contained 10 unique sentences per inflection; therefore, in total there were three sets of 40 sentences. Three sets were created to ensure a wide variation in items, and to avoid any potential item bias. There was no repetition of critical or target words across the three sets. For each set, half of the sentences for each inflection (total of five) were grammatical, whilst the other half were ungrammatical, such that a bare stem was presented in place of an obligatory inflected form (e.g. *yesterday the boy walk to school with his friends*). Two versions for each sentence set were created to counterbalance for grammaticality (i.e. sentences that were grammatical in set A were ungrammatical in set B and vice-versa), creating a total of six sentence sets: 1A, 1B, 2A, 2B, 3A, 3B.

All sentences were of equal length (mean length 8.83 words, standard deviation .99 words; mean syllables 11.82 per sentence, standard deviation 1.40 syllables per sentence). There were no significant differences between sentence sets with regards to the mean number of words ($F(2,117)=.03, p=.98$) or syllables ($F(2,117)=.18, p=.834$) per sentence. This was also the case for each of the four inflection types (words: $F(3,116)=.14, p=.934$; syllables: $F(3,116)=1.46, p=.229$).

All critical verbs and nouns that were manipulated for grammaticality were monosyllabic. The frequency of the verbs and nouns was controlled as research has shown this to affect grammatical performance (cf. Leonard, Davis & Deevy, 2007). There were no significant differences in the frequency (as specified by the Children's Printed Word Database (CPWD), Masterson, Stuart, Dixon, & Lovejoy, 2010) of the bare stem nouns and verbs between sentence sets ($F(2,117)=.03$, $p=.968$) or inflection type ($F(3,116)=1.65$, $p=.181$). In addition, the bare stem nouns and verbs were comparable with regards to the number of phonemes (sentence set: $F(2,117)=.16, p=.848$; inflection type: $F(3,116)=1.98$, $p=.121$) and phonological neighbourhood density (sentence set: $F(2,117)=.18$, $p=.838$; inflection type: $F(3,116)=1.86$, $p=.140$), as specified by the CPWD (Masterson et al., 2010).

As this experiment used a word monitoring task, a target word was required for each sentence that immediately followed the critical word – a verb or noun that was manipulated for grammaticality (as determined by the presence or absence of an obligatory inflection). It was ensured that no words within each sentence were acoustically similar to the target to limit the possibility of false alarm responses. In addition, the target words were controlled for on the basis of frequency, number of phonemes and phonological neighbourhood density. There were no significant differences (based on CPWD, Masterson et al., 2010) between sentence sets (frequency $p=.258$, phonemes $p=.906$, neighbourhood density $p=.459$) or word classes (frequency $p=.301$, phonemes $p=.934$, neighbourhood density $p=.397$). Finally, the position of the target word was systematically varied within each sentence set to prevent children from learning where the target word occurred, and to prevent phonetic saliency bias when inflections are in sentence-final positions (cf. Hsieh et al., 1999). However, it was ensured that the variation in target word positioning did not differ between sentence sets ($p=.978$) or word classes ($p=.947$).

As it can be seen, strict controls were implemented for stimuli frequency, phonological neighbourhood density, phoneme count, sentence length and position of target words. In view of this, it was expected that any differences in grammatical awareness should have been due to the experimental manipulation, rather than other confounding variables.

All stimuli for this experiment are detailed in Appendix A.

3.2.2.1 Recording, editing and presentation of the experimental stimuli for the word monitoring task. The target words and associated sentences were recorded and edited in the manner outlined in chapter 2. Sentences were spoken at a steady rate, with a mean of 166 words per minute (an 'average' rate as defined by Pimsleur et al., 1977 in Tauroza & Allison, 1990).

As detailed in chapter 2, all children received the same standardised instructions and had two practice trials. The first practice was under normal listening conditions. The second trial was with a new sentence, and was under a speeded condition that matched their allocated cognitive stress condition (i.e. if the child was allocated to the 20% speeded condition, the second practice used a sentence that was compressed by 20%; if the child was in the baseline condition, their second practice was under normal conditions for a second time). For the second practice trial in the speeded conditions, the following instructions were given:

> *We are going to do the same again, but this time the sentence will be spoken a little faster. Remember to press the spacebar when you hear the special word in the sentence.*

Once children had successfully completed both practices, they moved on to the experimental stimuli.

The speed of stimulus presentation was the main experimental manipulation of this experiment. Sentences were presented to children at either 0% rate of compression (control condition, normal rate), 10%, 20% or 30%. Sound compression was achieved through the functions in PRAAT (Boersma, 2001), which changes the tempo of the sound file without altering the pitch. It is important to note that the target word for each sentence was initially presented at a normal rate of articulation to ensure maximum auditory perception; only the sentence containing the target word was manipulated for speed. Figure 3 clarifies the presentation.

Chapter 2 provides a more detailed account of how the stimuli were presented to the children.

3.2.3. Design. Group membership (speed rate: 0%, 10%, 20%, 30%) was a between-subjects variable. Grammaticality (grammatical, ungrammatical) and inflection type (regular past tense, third person singular, regular plural, progressive) were within-groups variables. Therefore, any given child heard 40 sentences (10 per inflection, half grammatical and half ungrammatical) at one speed rate.

3.2.4. Procedure. Children were visited in their school during normal teaching hours. On the first visit, children completed the initial screening tests. Those children who passed the initial screening (i.e. achieved age-appropriate scores on all measures) were seen for a second time to complete the experimental part of this study, which comprised the word monitoring task and the basic auditory reaction time task. The basic reaction time task was always carried out before the word monitoring task in order to a) give children practice with a task requiring a speeded response and b) to increase intraparticipant reaction time stability (cf. Montgomery & Leonard, 2006).

After completing the basic auditory reaction time task, children were presented with the word monitoring task (see figure 3 and section 2.1).

3.3. Results

3.3.1. Data Preparation. Before analysing the data, it was necessary to calculate children's reaction times to the target words. This was done from the onset of the target word; the location of this was determined by examining changes in the auditory waveform using Audacity.

Once all reaction times had been calculated in this way, 'false' data points had to be addressed. Firstly, all responses made before the onset of the target word (i.e. negative reaction times) were removed and classified as 'false alarm' responses. Next, all failures to respond (denoted by reaction times of zero) were removed and treated as 'non-responses'. Of all responses, 15.23% were false alarms and 5.11% were classified as non-responses. Each child's mean reaction time as a function of grammaticality and word class was calculated using the remaining valid data points. This was then inserted into any blank cells derived as a result of this data verification to achieve a complete data set for each child (cf. Fazio, 1990). For instance, if a child's false alarm response was removed for an ungrammatical noun construction, that child's overall mean reaction time for valid ungrammatical noun trials was inserted into this cell.

Initial inspection of the data revealed ceiling effects in the noun stimuli. The children performed exceptionally well on the noun items in this experiment, with a mean accuracy of 99% in the control (0%) condition and 96% in the 30% compressed (most difficult) condition. In addition, there was very little variation between the grammatical and ungrammatical noun items; that is, children responded incredibly quickly to the targets following the noun critical word regardless of whether the critical word was grammatical or ungrammatical. This high performance level is possibly due to nouns having a much earlier age of acquisition than the verb stimuli items (e.g. Bates et al., 1994; Guasti, 2002), and children thus having highly robust lexical representations for these items. Indeed, the noun stimuli were all of high frequency in this experiment (e.g. 'dog' and 'ball'). For this reason, it was decided to remove the noun items from the remaining analyses to avoid any bias in results.

3.3.2. Auditory Reaction Time Task.

3.3.2. Auditory Reaction Time Task. All children performed the basic auditory reaction time task with 100% accuracy. A one-way independent measures ANOVA showed that the mean basic auditory reaction time for each of the four groups did not significantly differ (see table 5 for descriptive statistics; $F(3,96)=.32, p=.809$). In view of this, reaction time was not used as a covariate in the remaining analyses.

Table 5: Mean basic auditory reaction time as a function of group (exp. 1)

Group	Mean auditory reaction time (ms) (SD in ms)
0%	374 (147)
10%	354 (144)
20%	334 (150)
30%	365 (163)

3.3.3. Word Monitoring Task

3.3.3.1 Accuracy analyses. For the purposes of this experiment, 'accuracy' is defined in relation to the proportion of false alarms and non-responses in the word monitoring task. A child with 100% accuracy in this task would not have given any false alarms or non-responses; rather they would have provided a valid reaction time for each target word in their assigned sentence set. It is important to assess accuracy in the word monitoring task for two reasons. Firstly, it needs to be determined whether poor accuracy in the word monitoring task is due to a speed-accuracy trade-off, or due to an induced impairment in inflectional awareness. Secondly, children with SLI are more inaccurate than controls in the word monitoring task (Montgomery, 2005). As such, analyses can be conducted to see if an SLI-type profile of word monitoring task *inaccuracy* had been simulated in the typically-developing participants.

As three sentence sets were used throughout data collection, it was important to conduct a set analysis to ensure there was equal performance across sets, and to rule out the possibility that one set was more difficult than another. The proportion of false alarms and non-responses were combined to form one 'error rate' variable (cf. Montgomery, 2005). A one-way ANOVA revealed no effect of sentence set upon overall mean error rates ($F(2,97)=1.55, p=.216$). Consequently, sentence set did not need to be considered as a variable in subsequent accuracy analyses; data could be collapsed across all three sets.

Table 2 details the overall mean error rates for each group, as a function of grammaticality and inflection. From looking at table 2, it appears that error rates are reasonably similar throughout. A 4 (speed: 0%, 10%, 20%, 30%) x 2 (grammaticality: ungrammatical, grammatical) x 3 (inflection: past tense, third person singular, progressive) mixed ANOVA revealed a main effect of speed (f (3,96)=3.94, p=.010), with post-hoc Bonferroni tests showing only a significant difference in error rates between the 0% and 20% speeded conditions (p=.005). From looking at table 2, it appears that the normal rate (0%) of stimulus presentation was associated with slightly more errors than the 20% condition. No significant main effects of grammaticality ($F(1,96)=1.67, p=.200$) or inflection type ($F(2,192)=.39, p=.68$) upon error rates were found. In addition, there were no significant group*grammaticality ($F(3,192)=1.18, p=.321$), inflection*grammaticality ($F(2,192)=3.04, p=.050$) or inflection*grammaticality*group ($F(6,96)=.34, p=.914$) interactions.

Table 6: Mean combined error rates (false alarms + non-responses) as a function of speeded condition. Note that scores are out of a possible 40 (exp 1)

Speeded condition	**Mean overall error rates (SD)**
0%	1.07 (0.15)
10%	0.85 (0.11)
20%	0.62 (0.12)
30%	0.86 (0.07)

3.3.3.2 ***Reaction time analyses.*** Despite the removal of false alarms and non-responses from the reaction time data, the data remained skewed. In addition, a visual inspection of the data revealed several outlying (but genuine, rather than a loss of concentration) long response times. The data were therefore subjected to a log transformation, which reduces skew, normalises distributions and reduces the impact of long reaction times (Ratcliff, 1993). The statistics presented from this point forward are based upon log-transformed data points, unless otherwise stated.

As with the accuracy data, a set analysis was conducted to ensure similar reaction time variation across the three sentence sets. A one-way ANOVA showed no effect of sentence set upon mean log-transformed reaction time scores ($F(5,94)=.37, p=.871$). Because of this, sentence set has been disregarded as a variable in the remaining analyses.

3.3.3.2.1. *Speed of reaction times.* A one-way independent measures ANOVA was conducted on overall mean log-transformed reaction times, with speeded condition as the independent variable (four levels: 0%, 10%, 20%, 30%). The data are shown in table 7. It was found that speed of stimulus presentation had no effect upon the time taken to respond to the target words ($F(3,96)=.29, p=.834$). This suggests that, regardless of stimuli input rate, children were responding to the target words with equal speed.

Table 7. Mean log-transformed reaction times (in ms) as a function of speeded condition. Reaction times are collapsed across grammaticality and inflection type (exp 1).

Speeded condition	Mean reaction times (SD)
0%	2.84 (0.27)
10%	2.77 (0.20)
20%	2.84 (0.25)
30%	2.70 (0.23)

3.3.3.2.2. Grammaticality sensitivity. One of the main aims of this experiment was to investigate how speeding stimuli input rate affected a child's ability to implicitly detect ungrammaticality within sentences, as measured by the word monitoring task. A significant difference in reaction times between grammatical and ungrammatical sentences suggests processing of grammaticality. Conversely, if there is no grammatical-ungrammatical reaction time discrepancy, a lack of inflectional processing is implied (see Tyler, 1992).

A 4 (speed: 0%, 10%, 20%, 30%) x 2 (grammaticality: ungrammatical, grammatical) x 3 (inflection: past tense, third person singular, progressive) mixed ANOVA was carried out on the log transformed reaction time data. The results revealed a main effect of grammaticality ($F(1,96)=82.40, p<.001$), such that grammatical sentences were responded to faster (mean raw reaction time 672ms, SD 99ms; mean log reaction time 2.83ms, SD 1.99ms) than ungrammatical constructions (mean raw reaction time 798ms, SD 144ms; mean log reaction time 2.90ms, SD 2.16ms). However, there was a significant grammaticality*speed interaction ($F(3,96)=3.94, p=.011$), which can be seen graphically in figure 5. From looking at figure 2, it appears that there is a grammatical-ungrammatical discrepancy (i.e. evidence of inflectional processing) in all but the 30% speeded conditions. There was no overall main effect of speed (F(1,96=1.87,p=.139). In addition, the inflection*grammaticality ($F(2,192)=1.89, p=.154$) and inflection*grammaticality*speed ($F(6,96)=1.04, p=.400$) interactions were nonsignificant.

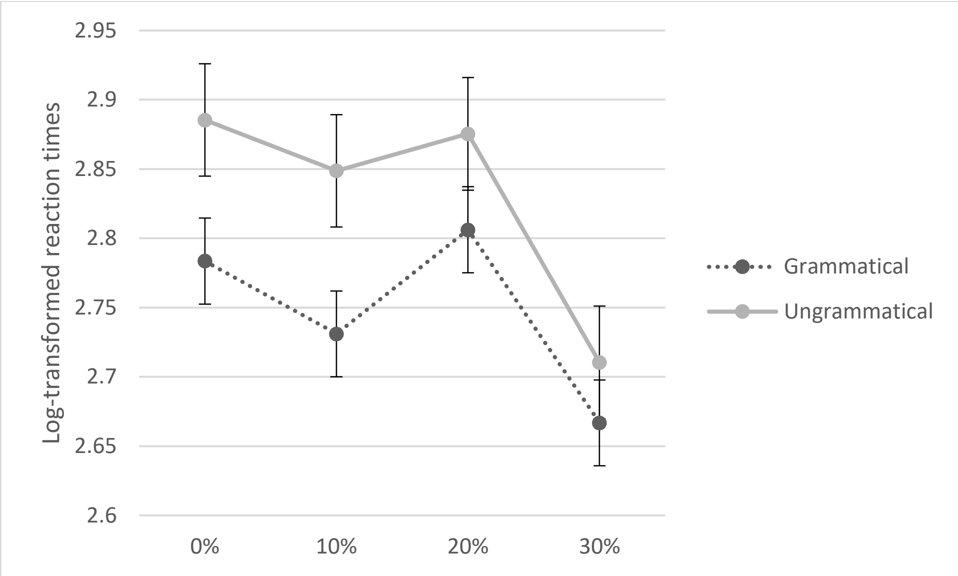


Figure 5: Log-transformed reaction times to target words as a function of speeded condition and grammaticality, collapsed across inflections. Error bars represent standard error. (exp 1).

To further understand the significant interaction, and to investigate the specific predictions with regards to inflections in more depth, a series of paired-samples t-tests (adjusted for familywise error rates) were conducted for each inflection, as detailed in figures 6,7 and 8 (significance values denoted in table 7). As it can be seen, at normal (0%) and 10% rates of stimulus presentation, children appeared to be aware of ungrammaticality in constructions assessing all three inflections (i.e. there was a significant grammatical-ungrammatical reaction time discrepancy). When the stimuli were speeded by 20%, children became less able to detect ungrammaticality in the regular past tense. This remained when stimulus presentation rate was compressed by 30%, and the third person singular inflection became significantly impaired at this rate too. The progressive inflection remained robust throughout the speeded conditions.

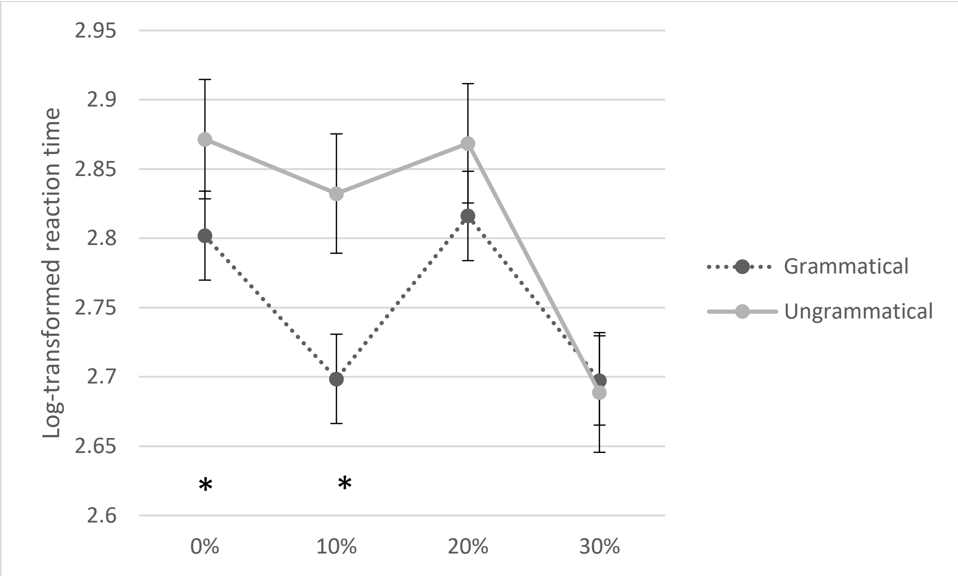


Figure 6: reaction times to target words in **past tense** constructions, as a function of speeded condition and grammaticality. Asterisks denote a significant difference between grammatical and ungrammatical data points at the p=.016 level (adjusted for familywise error rates). Error bars represent standard error (exp 1).

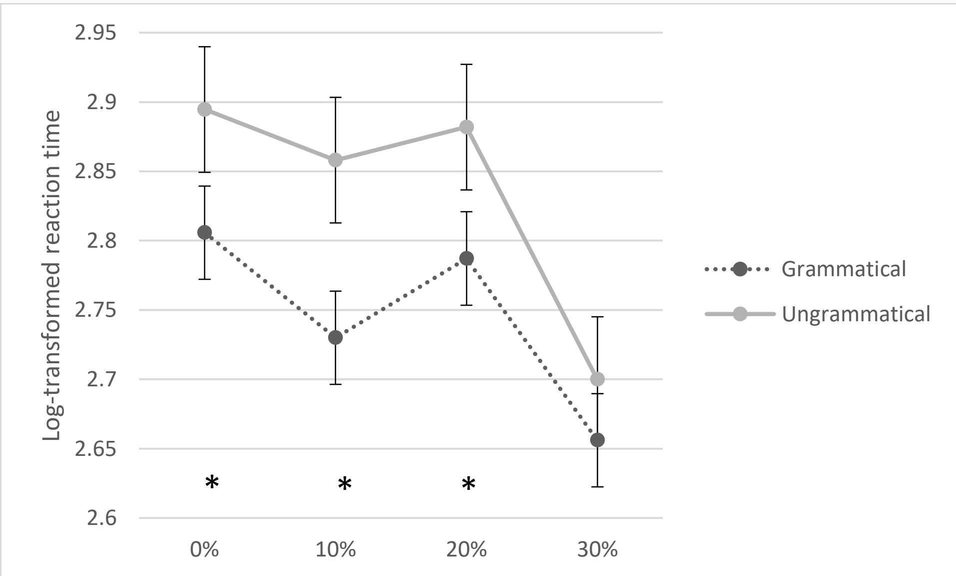


Figure 7: reaction times to target words in **third person singular** constructions, as a function of speeded condition and grammaticality. Asterisks denote significant difference between grammatical and ungrammatical data points at p=.016 level (adjusted for familywise error rates). Error bars represent standard error. (exp 1)

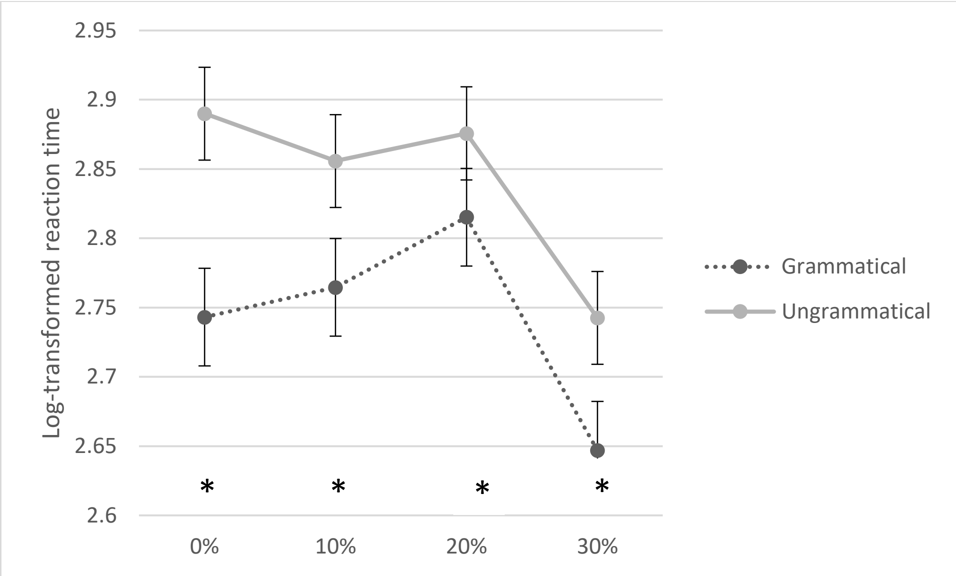


Figure 8: reaction times to target words in **progessive** constructions, as a function of speeded condition and grammaticality. Asterisks denote a significant difference between grammatical and ungrammatical data points at the p=.016 level (adjusted for familywise error rates). Error bars represent standard error (exp 1)

Table 7*:* Significance values for paired-samples t-tests assessing grammatical-ungrammatical reaction time discrepancy. * denotes significance at the p=.016 level (adjusted for familywise error rates) (exp 1)

Speed	**Inflection**		
	Past tense (figure 6)	Third person singular (figure 7)	Progressive (figure 8)
0%	.011*	.001*	.000*
10%	.000*	.003*	.001*
20%	.151	.002*	.000*
30%	.894	.041	.014*

3.4. Discussion

This experiment aimed to explicitly test the speed of information processing account of the inflectional difficulties seen in SLI by simulating such grammatical impairment in typically-developing children. An online word monitoring task was used to assess implicit awareness of four inflections (regular past tense, third person singular, plural and progressive) when stimuli placed stress on children's speed of processing. Generally speaking, an SLI-like profile of inflectional impairment was simulated in typically-developing children by stressing their speed of processing, at least within the confines of the past tense, third person and progressive inflections.

Several specific hypotheses were posed: Firstly, it was predicted that speeding sentence rate would lead to an increased accuracy in the word monitoring task, as compared to a normal rate of stimulus presentation. Secondly, it was hypothesised that an increased rate of stimulus presentation would decrease (i.e. improve) reaction times to the target words. Finally, it was predicted that a hierarchy of inflectional impairment would be induced in the typically-developing participants as a result of speeded stimulus presentation rate. Specifically, this hierarchy was expected to reflect what is seen typically in SLI: the regular past tense is most impaired, followed by the third person singular and then the regular plural. The progressive remains unimpaired in SLI, and should have therefore have remained robust in the face of increased stimulus presentation speed. The exact speed that would most accurately simulate SLI was expected to be either 20% or 30%, based on the Generalised Slowing literature.

For clarity, this discussion will begin by discussing the noun stimuli that had to be removed from the analyses, before moving on to cover the results in relation to the experimental hypotheses.

3.4.1. Noun Stimuli. In the results section, it was explained that the noun items (which assessed awareness of the plural inflection) were removed due to ceiling effects. The children in this experiment performed exceptionally well on the noun items, even in the fastest condition. As such, there was a lack of variation in the data and results were consequently confounded.

The excellent performance on the nouns in this experiment was perhaps due to such lexical items having a much earlier age of acquisition than the comparative verb items (e.g. Bates et al., 1994; Guasti, 2002), probably because of their relative ease as compared to verbs (see 1.3.3.2 for a discussion). Children were therefore likely to be more familiar with nouns than verbs, and will inevitably have had more experience of nouns in their inflected form than verbs in their inflected forms. Consequently, it is possible that the participants had such robust lexical representations of the noun items that the speed stressor did not affect performance. The simple and highly-frequent nature of the stimuli only added to the robustness in the face of the speed stressor. In future, nouns that are lower in frequency to those in this experiment should be used, in order to try and avoid ceiling effects.

When one compares the noun and third person singular items in this experiment, it becomes clear that the inflectional difficulties in SLI are unlikely to be due to the perceptual saliency of the specific inflections. The plural and the third person singular are the same inflection at the phonemic level (-*s*). However, they are impaired to very different degrees in this study (the plural was associated with ceiling effects, even in the fastest (toughest) condition). It may simply be the case that, because nouns are learnt earlier than verbs (e.g. Bates et al., 1994; Guasti, 2002) and thus are experienced in their inflected form more frequently, children's lexical representations of nouns are so robust that they are unaffected by cognitive stress (or speed, at the very least).

Alternatively, it may be that whilst a general cognitive deficit plays a pivotal role in the grammatical difficulties in SLI, there is some weaker effect of grammatical features. As Hayiou-Thomas (2002) highlights, the plural inflection only speaks to one feature (number), whereas the third person singular speaks to three: tense, person and number. As such, the third person singular inflection is inherently more complex, and so may be more susceptible to impairment in the face of cognitive stress. In this sense then, it may be the case that an interaction between general cognitive mechanisms and the grammatical complexity of the inflection accounts for the specific deficits seen in SLI. This line of reasoning is similar to that proposed by Leonard and colleages' Surface Hypothesis (see Leonard, 2014 for a comprehensive review).

Finally, whist it is clear that the plural -*s* and the third person singular -*s* are the same *phoneme*, it cannot be concluded that they share the same *phonology*. Indeed, as Black and Chiat (2003) highlight, the regular plural -*s* is often louder and longer than the third person singular -*s*, and is often in the (salient) sentence-final position, which leads it to be relatively more phonologically salient. Although the position within the sentence was controlled in this experiment, the acoustic properties were not. Perhaps the plurals in this study were more phonologically salient, which might help explain the ceiling performance? Further research that controls for the phonological saliency (by way of controlling amplitude and duration) of the two -*s* inflections would help shed some light on this question, and tease apart the issue.

3.4.2. Accuracy. Data analyses revealed that error rates were reasonably similar across all speeded conditions. The only exception came between the error rates in the 0% and 20% speeded groups, whereby the normal rate of stimulus presentation (0%) was associated with slightly more errors than the 20% condition. This is a little odd, although an inspection of the descriptive statistics reveals that even in the 0% condition error rates were minimal (2.68%), and there was little variation within any speeded condition. Generally speaking, there did not appear to be any effect of speed of presentation rate upon accuracy; children remained highly accurate even in the fastest (30%) rate. The significant difference between the control and the 20% condition appears to be an artefact.

This finding did not support the hypothesis, and does not concur with previous literature finding that as sentence presentation rate was increased, typically-developing children became more accurate in the word monitoring task (Stark and Montgomery, 1995; Montgomery, 2005). However, an inspection of the accuracy data showed that error rates remained very low, even in the most difficult (30%) condition. There was also little variation in error rates, both within and between speeded conditions. Consequently, the results are likely to reflect ceiling effects.

In order to be accurate in the word monitoring task, an individual must simply provide a response to the target word. There is no complex processing involved (such as the processing of rapid morphemes); all the participant needs to do is recognise the target. The information processing demands are relatively minimal therefore in the word monitoring task, and it is reasonably easy to achieve high accuracy levels. In addition, the participants in this study were typically-developing children, with robust and well-developed lexical and grammatical systems. Finally, the sentence stimuli were of very simple construction and contained high frequency words. Given the ease of the task, the level of language ability of the participants and the simplicity of the stimuli, it is possible that the task was simply too easy in all speeded conditions, and so that is why ceiling effects were evident. In future, the sentences could be made more syntactically-challenging, or the stimuli could be of lower frequency, to increase task complexity and to give more variation in error analyses.

3.4.3. Speed of response. It was found in this experiment that speed of stimulus presentation had no effect upon the time taken to respond to the target words. That is, regardless of stimuli input rate, children were responding to the target words with equal speed. However, from looking at the data, it appears that there was a trend for reaction times to improve when stimulus presentation rate is increased. The figure shows that when stimulus presentation rate was compressed (especially by 10% and 30%, but also 20% to a very small degree), reaction times quickened, as compared to a normal (0% compression) rate of presentation. This trend supports hypothesis two, and also supports previous research. For instance, Stark & Montgomery (1995) and Montgomery (2005) noted that speeding sentence presentation rate by 25% led to faster word monitoring task reaction times for typically-developing children in their experiments. However, the effects in these studies were more clear-cut than in the current study.

As Montgomery (2005) noted, it is believed that this trend of quickening reaction times in the speeded conditions is because the faster sentences forced children to ‘up their game’, and to focus more on the task at hand, given its challenging nature. Conversely, reaction times were relatively slow in the baseline condition because the task may have been a little boring and unchallenging for the typically-developing participants of this study. Anecdotal evidence certainly suggests that this is the case.

3.4.4. Grammatical sensitivity. The primary aim of this experiment was to attempt to induce an SLI-like profile of inflectional impairment in typically-developing children. Although there was no significant three-way interaction (grammaticality*inflection*speed), a series of paired-samples t-tests showed interesting results. In these tests, it was found that normal and 10% faster rates of stimulus presentation were associated with awareness of grammaticality in the regular past tense, third person singular and present progressive inflections, as evidenced by significant grammatical-ungrammatical reaction time discrepancies. However, when stimuli were speeded by 20%, children became less able to detect ungrammaticality in the regular past tense inflection (i.e. there was a nonsignificant difference between grammatical and ungrammatical reaction times, as measured by the t-test). This impairment extended to the third person singular inflection too when stimuli were compressed by 30%. The progressive inflection remained robust in the face of increased speed of stimulus presentation, even in the fastest (30%) condition. These results demonstrate a very accurate simulation of the pattern of inflectional difficulty seen in SLI (i.e. most impairment in the regular past tense, followed by the third person singular, and no impairment in the progressive inflection). Whilst the need to exercise caution when discussing this pattern of results is acknowledged (as there was no significant three-way interaction), it is nonetheless very promising, and has important implications for predictions surrounding the mediating factors in the inflectional difficulties in SLI.

The grammatical sensitivity results support the hypothesis that an SLI-like pattern of inflectional difficulty will be ‘induced’ in typically-developing participants by means of increasing speed of stimulus presentation rate. In addition, the findings align well with pre-existing literature that has also shown simulation of a specific grammatical profile in typically-developing populations by introducing cognitive stress (e.g. Blackwell & Bates, 1995; Dick et al., 2001; Hayiou-Thomas et al., 2004; Kilborn, 1991; Miyake et al., 1994).

The results also concur with literature on the generalised slowing hypothesis, which suggests that children with SLI experience a rate of information processing that is between 14% and 33% slower than their peers (e.g. Kail, 1994; Miller et al., 2001; Windsor & Hwang, 1999). This study found that the past tense became impaired when stimuli was compressed by 20%, and that the third person also became impaired when the compression rate was increased to 30%. This indicates that the exact proportion of 'slowing' children with SLI experience may lie somewhere between 20% and 30%. This then concurs with the data from Montgomery's work (e.g. Montgomery, 2005), which found that the online linguistic skills of children with SLI were significantly improved when stimuli were slowed down by 25%.

3.4.5. Theoretical implications and considerations for future experiments. Whilst this study shows some promising results, there are some important questions raised by this experiment. Most notably, the results suggest that the inflectional difficulties of SLI may indeed be mediated by a deficit in speed of information processing. This finding lends clear support to the Generalised Slowing hypotheses of SLI.

This experiment is also the first of its kind to demonstrate that *online inflectional awareness* may be related to speed of processing. Whilst there literature demonstrating a link between speed of processing and both general online language processing (Montgomery & Leonard, 2006) and offline inflectional awareness (Witherstone, 2010), there has been no research to extend this idea to the online processing of inflections.

Despite the promising results, it must be remembered that speed was the only stressor used in this experiment. As such, it is unclear whether the results are because we stressed *speed* specifically, or because we introduced *some form* of cognitive stress. It may be the case that *any* cognitive stressor will result in SLI-like grammatical impairments. Likewise, it may be that speed is the 'key' stressor. To determine this, future experiments should be conducted that assess several different cognitive stressors in parallel.

3.4.6. Summary and conclusions. To summarise, this experiment was able to induce an SLI-like profile of inflectional impairment in typically-developing children by stressing speed of processing, at least within the confines of the regular past tense, third person singular and present progressive inflections. This suggests that the inflectional difficulties seen in SLI may well be mediated by impairment in the speed with which normal rate language can be processed, and so lends support to the idea that a general cognitive (speed of processing) deficit, rather than a specific linguistic one, plays a pivotal role in explaining the grammatical difficulties in SLI. Future work should investigate whether it is stress placed specifically on speed of processing that results in an SLI-like pattern of grammatical difficulty, or whether it is generalised cognitive stress.

The findings of this experiment, combined with previous literature, (tentatively) suggest that children with SLI may process information approximately 20%-30% slower than their typically-developing counterparts. Research that slows the rate of stimulus presentation down by such an amount for children with SLI may help to lend further support to this, provided it demonstrates that the grammatical skills of children with SLI can be improved by slowing down the signal.

The plural and third person singular inflections were associated with very different levels of performance, despite being the same inflection on a phonemic level. The differing performance levels, combined with previous literature, suggest that phonological saliency, grammatical complexity and/or age of acquisition may play some part in mediating the grammatical skills of children with SLI. However, it must be remembered that the noun stimuli were confounded by ceiling effects in this experiment, and the possibility of this needs to be minimised in future simulation studies to extend the application of the results to the literature.

This study made a unique contribution to the literature on three levels. Firstly, it was the first of its kind to assess the effect of speed of processing upon children's on-line awareness of specific inflections via a word monitoring task. Secondly, this is the first study to systematically and incrementally manipulate the cognitive stressor of speed in an experimental paradigm. Lastly, this study was the first to attempt to simulate the grammatical difficulties seen in SLI via an on-line task.

Overall, this study has some highly promising results that have implications for theory and methodology. It does successfully demonstrate a general cognitive deficit model of the grammatical difficulties in SLI, albeit limited to three inflections and one stressor. However, it must be remembered that this study used typically-developing participants. It did not demonstrate whether children with SLI do indeed have a speed of processing deficit, and whether this is causal in their grammatical weaknesses. In order to establish these two points, a study would need to be conducted that a) investigated speed of processing in children with SLI and b) attempted to reduce the grammatical impairments by means of easing speed of processing cognitive load (by slowing the signal, for example).

Chapter 4. Experiment 2: Verbal Short Term Memory, Auditory Perception and Speed of Processing

4.1. Introduction

The results of experiment 1 suggest that it is indeed possible to simulate an SLI-like pattern of inflectional morphology difficulties by stressing speed of information processing. Whilst this finding is promising, it is unclear whether speed was the 'key' stressor to simulate SLI, or whether stressing *any* cognitive system would result in the same findings.

Supporting the findings from experiment 1, there is a large body of literature that does suggest that the grammatical difficulties children with SLI experience may be due to a deficit in the speed with which language can be processed (see section 1.3.5.2 for a comprehensive review). However, there is also a substantial body of research that suggests that other cognitive domains may play a role in the deficits of children with SLI. The most notable ones in the literature (besides speed of processing) relate to deficits in phonological short term memory and auditory perception.

The nonword repetition (NWR) test is a strong, pure measure of phonological short term memory capacity (Gathercole & Baddeley, 1989), and is the most widely-used assessment of such in the literature. In the NWR test, participants hear nonwords, such as /*woogalamic*/, and are asked to repeat them verbatim. The nonwords vary in complexity with regards to length and phonotactic probability (the probability decreases in more complex instances). Archibald & Gathercole (2007) argue that the act of repeating nonwords is more demanding of phonological short term memory than, for example, the repetition of real words or numbers. This is because when recalling real words or numbers, one can make use of their long-term lexical knowledge to aid performance. As nonwords will not have been encountered before, long-term lexical knowledge plays little role in remembering these novel forms. Instead, an individual must call heavily upon the mechanism that stores individual word sounds: the phonological short term memory system.

The NWR test is a good simulation of the phonological aspect of real-word learning because new words are all phonologically novel when they are first encountered. The difference lies in the semantics – real-words hold meaning and nonwords do not. Supporting the assumption that the NWR test is representative of real-word learning is a bank of unequivocal evidence highlighting the link between NWR and language skills in both typical and atypical populations. For instance, there are strong correlations between performance on NWR tests and vocabulary use in typically-developing children (e.g. Gathercole & Baddeley, 1989; Gupta, 2003). In addition, experimental studies (e.g. Gathercole, Service, Hitch, Adams & Martin, 1999; Gupta, 2003) have demonstrated a significant positive correlation between a child's NWR performance and their ability to learn the phonological forms of new words. Interestingly, neither study found a link between NWR performance and the learning of the *semantic* meanings of the new words, suggesting a very specific relationship between NWR skills and phonological memory (rather than general vocabulary aptitude).

In a seminal paper, Gathercole and Baddeley (1990) identified that children with SLI performed significantly worse than their age-matched peers on a NWR test. Despite this deficit, the children with SLI performed as well as the control group in speech discrimination tests and measures of articulation rate, suggesting a very selective deficit in phonological skills rather than in generalised language. The finding that children with SLI demonstrate impaired NWR performance has since been extensively replicated, both with English-speaking children (e.g. Burke & Coady, 2015; Conti-Ramsden, 2003, Dollagham & Campbell, 1998; Edwards & Lahey, 1998; Montgomery, 2004; Rispens, Baker & Duinmeijer, 2015) and those from other languages (e.g. Swedish: Kalnak, Peyrard-Janvid, Forssberg & Sahlén, 2014; Dutch: Sahlén, Reuterskröld, Nettelbladt, & Radeborg, 1999; Italian: Dispaldro, Leonard & Deevy, 2013; French: Elin Thordardottir et al., 2011; Spanish: Girbau & Schwartz, 2007). In addition, the NWR deficit remains present even when children with SLI are compared to younger language-matched children (Edwards & Lahley, 1998; Montgomery, 1995), and when they appear to have 'resolved' their language difficulties (Bishop, North & Donlan, 1996; Botting & Conti-Ramsden, 2001). In view of the extensive evidence, NWR deficits are now regarded as a 'hallmark' of SLI (Roy & Chiat, 2004), and as a clinical marker of the disorder (Conti-Ramsden, 2003).

Given the widespread evidence base indicating a relationship between NWR performance and language skills in both typically-developing children and those with SLI, it seems logical to argue that the language difficulties children with SLI experience may be the result of impairments in phonological short term memory (as NWR performance relies upon such cognitive system). This is indeed the view of many researchers (e.g. Gathercole & Baddeley, 1990), and is particularly supported by the work of Montgomery (1995). In this study, Montgomery presented a sentence comprehension task to children with SLI and language-matched controls. The length of the sentences was manipulated such that they were either short or long (by including redundant information, often adjectives). It was found that children with SLI performed worse than language-matched controls on the long sentences, and that this long sentence performance was significantly correlated to NWR ability. There was no differential performance between the two groups for the short sentences. Montgomery's (1995) research therefore not only shows that children with SLI may have a phonological working memory deficit (over and above what is to be expected given their general language aptitude), but that it may mediate language skills in the disorder.

Extending on from this, there is a good body of literature that highlights instances when phonological language deficits appear to be mediated by deficits in general short term memory. For instance, Archibald and Gathercole (2006) found that children with SLI performed worse than age-matched controls on digit and word span – both of which are 'traditional' measures of short term memory. In addition, Baddeley and Wilson (1993) noted that adults with acquired deficits in generic short term memory had very impaired NWR performance, and struggled to learn the phonological forms of new words, despite being able to learn their semantic properties (children with SLI demonstrate profound deficits in phonology, whilst semantic knowledge is often unaffected, Leonard, 2014). Finally, Papagno and Vallar (1992) conducted an experiment whereby typically-developing adults demonstrated impaired word learning (with regards to the phonological form) under conditions of short term memory stress.

In view of all of the evidence presented thus far, it appears that children with SLI do indeed demonstrate NWR deficits, which seem to be a reflection of a more general deficit in phonological short term memory. Deficits in phonological short term memory appear to mediate general language aptitude, especially with regards to the phonological forms of words. Despite this logical train of thought, there are some challenges that need to be considered. Firstly, there is some contradictory evidence: Snowling (2006) for example found evidence for dissociations between NWR and vocabulary knowledge in language-impaired samples. Also, there is a significant degree of heterogeneity with regards to phonological memory deficits in SLI, and there are a large proportion of children with SLI who show no NWR impairment (Catts et al., 2005). Finally, Montgomery (2000) found that phonological memory did not correlate with word monitoring task performance in SLI, language-matched or age-matched control groups. These contradictory findings question the relationship between phonological memory and language aptitude, and beg further research in the area.

In addition to the contradictory literature, some research suggests that the NWR deficits of children with SLI appear to be more than simply problems with general short term memory: Archibald and Gathercole (2006) noted that all 20 children with SLI in their study demonstrated a NWR deficit, but only 14 of those children showed general short term memory deficits, as measured by digit and word serial recall. This point calls to a more fundamental issue: what exactly does NWR measure? From these findings, it appears to measure more than simply short term memory, and it does indeed seem that the deficit in SLI may extend beyond this, too. Archibald and Gathercole (2007) support the idea that the language difficulties of children with SLI may be mediated by more than just short term memory. They found that whilst children with SLI showed marked impairments in both standard serial recall and in NWR as compared to chronological-age matched controls, their NWR deficit was greater than the serial recall deficit, and it persisted even when short term memory was controlled.

Despite the contradictions explored above, there remains a strong possibility that phonological working memory deficits play a central role in the difficulties experienced by children with SLI. Thinking theoretically, the question stands of how these deficits explain the very specific pattern of inflectional deficits evident in the disorder. Montgomery (1995) noted that although children with SLI were worse than language-matched controls on a NWR task, they demonstrated the same effects as controls with regards to nonword phonological similarity. That is, lists of phonologically-similar nonwords were recalled less accurately than lists of nonwords that were phonologically-dissimilar. Montgomery (1995) suggested that, based on these findings, children with SLI may have difficulties storing and maintaining phonological information, rather than encoding it. If children with SLI do indeed have trouble storing and maintaining phonological information, it seems reasonable to think that inflectional morphology will be impaired, as one needs to pay close attention to the phonology of a word in order to extract the (phonologically weak) inflections. This then speaks to the phonological properties of inflections, and Leonard's Surface Hypothesis (see section 1.3.5.2.2). That is, inflections that are less phonologically salient, such as the regular past tense –ed are more susceptible to 'damage' than those that are more salient (e.g. the regular plural –s).

However, Montgomery's (1995) SLI sample demonstrated worse phonological discrimination skills than their language-matched counterparts, which possibly suggests some level of auditory perception deficit. This is supported by the results of Steenbrugge and Chiveralls (1994), which showed children with SLI to have worse real-word and nonword phonological discrimination skills, as compared to controls. Consequently, the NWR deficits that are so endemic in SLI may be the result of a more general auditory perception weakness, which results in poor phonological representations, rather than a primary phonological memory deficit.

The work of Ziegler et al. (2005) provides strong evidence for a general auditory perception deficit in SLI, by showing that children with SLI demonstrate speech perception difficulties when the stimuli is masked by noise (and thus has a degraded auditory quality). In their study, Ziegler and colleagues tested French children's (SLI mean age 10.4years, language match group mean age 8.6years, age matched group mean age 10.6years) ability to detect consonantal categories under optimal (silent) and masked noise conditions. It was a forced-choice task, whereby participants heard vowel-consonant-vowel sequences and had to choose from a visual display what they just heard. There were two types of noise mask used: temporally-fluctuating and stationary. Both noise masks were on the same spectrum as running speech (i.e. pink noise). It was found that in the control (silent) condition, children with SLI were slightly worse at consonantal perception than their age-matched peers, but were comparable to their language-matched peers. When looking at the fluctuating and stationary noise as individual elements, Ziegler and colleagues found children with SLI to have worse consonantal category detection than both age- and language-matched controls in both noise conditions, with deficits being more pronounced in the stationary (rather than fluctuating) noise condition. This suggests that children with SLI are more affected by noise than their TD peers, even when language ability is considered. An analysis of scatter plots revealed the vast majority of the SLI sample evidenced some level of significant auditory perception deficit. In addition, regression analyses showed speech perception deficits to significantly predict severity of language performance on both real word and nonword repetition tasks. Considering all of these points, issues with speech-in-noise processing may indeed be a significant issue in children with SLI.

The findings of Ziegler et al. (2005) contradict some studies that dispute a wide-spread auditory deficit in SLI samples (see section 1.3.5.2.3). However, as Ziegler and colleagues point out, the majority of studies that investigate speech perception and find no deficit do so under optimal listening conditions. As the aforementioned research has found, it is speech-in-noise that children with SLI may struggle with. Indeed, assessing speech-in-noise is more representative of daily life (e.g. classroom/playground environments) than assessing under optimal conditions. A number of other studies support the finding that children with language-learning disorders evidence speech perception deficits when a noise mask is present, but not in silence (see section 1.3.5.2.3).

As Ziegler et al. (2005) highlight, it has been argued that SLI is not the result of an auditory deficit. Specifically, researchers have argued that 1) auditory deficits are correlational and not causal in SLI 2) only a minimal amount of children with SLI have auditory processing problems and 3) any auditory deficits that do exist do not predict language performance (see 19 for review). According to Ziegler et al. (2005), their findings refute all three points: 1) there was a significant auditory perception deficit in SLI even when language was taken into account by comparing to a language-matched group 2) the vast majority of the SLI sample showed an auditory processing deficit and 3) regression analyses showed a predictive relationship between language and auditory performance.

Although Ziegler et al. (2005) established some interesting findings, their study is not without flaws. As Ziegler et al. (2011) highlight, the stimuli were all 16 consonantal arrangements in the French language, and the foils in the response task were other valid consonantal arrangements. This increased the complexity of the task, adding in decision effects and response biases (Macmillian & Creelman, 2005). In addition, participants were required to read the responses for selection, which may have confounded the results, especially given that children with SLI often experience co-morbid literacy difficulties (e.g.Catts et al., 2005).

In view of these points, Ziegler et al. (2011) set out to replicate their 2005 findings using a ‘criterion free’ design that was free of the confounding variables in their 2005 paper. Specifically, the 2011 paper used an “AXB task” to assess speech perception of consonantal stimuli. In this task, children were given option A, the target, and then option B. They then had to say whether A or B was closest to the target. This method minimises memory load as the target is between the two options, and is highly appropriate for child experimental linguistic research (Sutcliffe & Bishop, 2005). Broadly speaking, Ziegler and colleagues (2011) supported their 2005 findings: They found children with SLI showed speech perception deficits in silence and in pink noise, as compared to chronological age-matched controls (note that there was no language-matched group in this study). Performance of all children was better with a fluctuating noise mask, as compared to stationary.

In both the 2005 and 2011 studies, Ziegler and colleagues showed evidence of children making use of glimpses, by discussing a phenomenon called ‘release from masking’ (RFM) which is evidenced by better performance when stimuli are masked by a fluctuating noise, as compared to a stationary noise. This effect suggests that listeners maximise processing when the noise is not present or ‘dipping’ in the fluctuating masks, and demonstrates the existence of adequate temporal and spectral processing skills (temporal resolution is used in a masked task to extract speech during the noise (Peters et al., 1998) and spectral resolution is used to process speech during the silent parts of the signal (Hopkins & Moore, 2009). Participants with sensorineural hearing loss show impaired temporal and spectral resolution, and also do not show a RFM effect (e.g. Peters, Moore & Baer, 1998), supporting the idea that both temporal and spectral skills are required if one demonstrates RFM.

Ziegler et al. (2005) found a RFM effect of about 10% (i.e. 10% better performance in fluctuating than stationary noise) in all three groups with a lack of interaction, suggesting the size of RFM effect was similar for all three groups. This was replicated by the 2011 research. The fact that the SLI group showed a RFM effect to the same *extent* as controls suggests they have intact lower-level temporal and/or spectral processing skills, as RFM deficits are largely attributed to low-level temporal and/or spectral impairments (Nelson & Jin, 2004).

Taken together, the two studies conducted by Ziegler and colleagues (2005, 2011) suggest that children with SLI have intact low-level auditory perception abilities, and that their difficulties may lie in *auditory feature extraction*. That is, it may be the case that children with SLI are "generally inefficient at processing the information underlying speech identification and that such inefficiency is exacerbated by the adjunction of background noise" (p 14115).

Although Ziegler's (2005, 2011) work goes some way in highlighting auditory perception deficits in SLI, it falls somewhat short. In both studies, the stimuli were simple consonantal categories. Sentence stimuli need to be used if the task is to accurately reflect real-world language processing. Also, Ziegler uses a fluctuating noise mask (as well as a stationary one), which masks the underlying speech signal at varying amplitudes throughout the signal's duration. The purpose of this was to assess whether children with SLI experience a RFM effect, which would serve to establish whether these children had low-level auditory impairments. However, speech is naturally fluctuating in amplitude, with some aspect of a sentence, particularly inflections, being very weak in phonological salience relative to the rest of the signal. As the intensity of the fluctuations was random, it may have been the case that the acoustically-weaker parts of the stimuli were masked by the more intense parts of the noise mask. This would lead to a phonological disadvantage - that is, children may have struggled in the consonantal identification task not because of an auditory deficit, but because the noise mask was especially 'loud' over the quieter, more critical parts of the stimuli. Using a noise mask that was signal-correlated would overcome this: A signal-correlated noise mask is fluctuating in amplitude, but these fluctuations follow the underlying speech signal. The noise mask is quieter over the quieter parts of the sentence, and is louder over the louder parts. This ensures that each phoneme of the underlying sentence is masked with equal signal-to-noise intensity.

Finally, and more theoretically, if the language difficulties of children with SLI are mediated by a difficulty with feature extraction when faced with a noisy environment, the question remains of how exactly (if at all) can this explain the specific pattern of inflectional difficulty seen in the disorder? Indeed, whilst the work discussed here suggests an auditory processing deficit to be central to SLI, it does not look at specific inflectional processing which, according to Leonard (2014), is the most fundamental deficit children with SLI demonstrate.

Although Ziegler's work fails to assess *inflectional* difficulties, there is some evidence from experimental simulation studies that suggests a deficit in auditory perception can result in a morphological impairment. In an early simulation study, Kilborn (1991) compared sentence comprehension in typically-developing English and German adults, when the sentences were presented in optimum and stationary noise-masked (pink noise) conditions. In the optimum (no noise) condition, the English participants made use of word order to perform the task, whereas the German speakers made use of morphological cues. The performance of the English speaking participants was not affected by the noise mask; however the German speakers began to struggle, and shifted their strategy from using morphological information to using word order cues. This suggests that a cognitive stressor that causes a noisy environment can negatively impact upon inflectional processing.

Supporting the work of Kilborn (1991), Dick et al. (2001) has also demonstrated that general cognitive stressors can induce specific grammatical deficits in TD adults performing a sentence comprehension task. The researchers used a variety of stressors, including a pink stationary noise mask (50% signal to noise ratio), low-pass filter (at 600Hz to degrade the auditory quality) and speech rate compression (to 50% of the original rate). It was found that the noise mask, filter and speech rate compression all induced Broca's Aphasia-like grammatical (sentence comprehension) impairments in the TD participants.

Ziegler and colleagues (2005, 2011) spoke in some detail about the importance of studies reflecting real-world environments, and that speech-in-noise is very important to study in children with SLI as they are faced with noisy environments, such as classrooms and cafeterias, on a daily basis. However, the noise mask used in both their 2005 and 2011 experiments, as well as the work of Kilborn (1991) and Dick et al. (2001) was pink noise. Although this is on the same spectrum as running speech, it is not quite the same and still sounds much like ‘static’ noise. What would be even more representative of a child’s everyday noisy environment would be a ‘multi-talker babble’ (or ‘cafeteria’) noise mask. This type of noise mask reflects exactly the sort of background noise that a child would have to extract speech signals from on a daily basis. In addition, it has been discussed in section 1.3.5.2.3 that one needs to consider the amplitude of the underlying speech signal when introducing a noise mask. Speech is naturally fluctuating in amplitude, and inflections in particular are very quiet with regards to amplitude. A noise mask will therefore mask the quieter parts of the sentence with more relative intensity than the louder parts of a sentence, leading the inflections to suffer more relative masking. No study presented here has controlled for this; a signal-correlated noise mask would do so.

As an interim summary, it appears that there is a good body of evidence that supports both phonological short term memory and auditory perception (speech-in-noise) deficit accounts of SLI. However, there is some counterevidence to each hypothesis and some problems with the key studies, and it remains unclear as to how exactly (if at all) these deficits result in the specific pattern of inflectional difficulty seen in SLI. Consequently, more work is needed that tests these hypotheses in an experimental way.

In addition to the need for more evaluation of the hypotheses, there are some large gaps in the literature that need to be filled. Firstly, there is a significant lack of research assessing language and grammar skills using an online task. All of the research presented in this chapter has used offline measures of language performance, such as sentence comprehension (e.g. Mongomery, 1995; Dick et al., 2001) or the AXB task (Ziegler, 2011). To date, there is no known research that has assessed *online* language skills under noise masked conditions, nor is there research that assesses how either of the hypotheses (phonological short term memory and auditory perception) speak to the *grammatical* deficits in SLI. In addition, the noise-masks used in the literature need to be improved on two levels: 1) they need to control for the relative signal-to-noise ratios and mask the weaker (inflections) part of the sentences with less relative intensity by being signal-correlated and 2) they need to be truly representative of real-world environments by featuring multi-talker babble.

In view of the points raised above, this study will assess the phonological short term memory and auditory perception deficit accounts of SLI using an online word monitoring task which assesses grammatical sensitivity. The speed of processing account will also be re-investigated for the purpose of replication of experiment 1.

Another important question raised by experiment 1 was the comparison between the plural *-s* and the third person singular *-s*. The inflections are the same, phonemically-speaking. However, they are impaired to very different degrees in SLI, and were associated with very differing levels of performance in experiment 1 (nouns are least impaired in both cases). When we look at the data from experiment 1, it can be seen that the nouns were associated with very fast response times in the word monitoring task, regardless of grammaticality. These ceiling effects confounded the results and consequently the nouns were removed from the analyses. It was argued in section 1.3.3.2 that this was possibly because nouns are inherently easier to acquire than verbs, which would lead to extremely robust lexical representations (and thus fast reaction times) in the typically-developing participants.

The age of acquisition argument above seems plausible, but it only really speaks to learning of the bare stem noun or verb; it doesn't explain why the regular plural *-s* is less impaired than the third person singular *-s*, unless it is simply a case of frequency of exposure. That is, because nouns are acquired earlier than verbs, children hear them more in their inflected forms, and have more practice inflecting them themselves. Alternatively, it may be the case that the plural-third person discrepancy may be due to subtle phonological features. Research has shown that the regular plural *-s* tends to be longer in duration and amplitude than the third person singular inflection (see Black & Chiat, 2003 and Leonard, 2014 for discussions), which leads to it being higher in phonological saliency, despite being the same *phoneme*. Hsieh, Leonard and Swanson (1999) also identified that the regular plural -*s* is often found in sentence-final positions, whereas the third person singular is not, which would also lead to a more phonologically-salient inflection. Perhaps then, the regular plural is less impaired than the third person because it is more phonologically salient. This argument is a significant feature of the Surface Hypothesis of Leonard and colleagues (see 1.3.5.2.2 for a detailed overview).

In view of the questions surrounding the plural-third person discrepancy, this study looked to compare the grammatical sensitivity to these two inflections once phonological saliency had been controlled (as far as was practically possible). Specifically, the stimuli in this study were paired into homophones, such that they were both nouns and verbs (inflected using the regular plural and third person singular respectively) depending on the sentence context. For example, the word */tie/* can be both a noun (an item of clothing) and a verb (to bind something). The amplitude and duration of the two inflections within each pair were also matched, to ensure that one was not more phonologically-salient than the other (Sorenson, Cooper & Paccia (1978) and Davis, Morris & Kelly (1992) both identified that nouns are longer in duration than verbs, even in the case of homophones). To date, there is no known study in the field that has matched the regular plural and third person singular inflections for phonological saliency on this level, and so this study has an important place in the literature.

As a summary, this experiment investigated the phonological short term memory, auditory (speech-in-noise) perception and speed of processing deficit accounts of SLI, with a particular focus on the regular plural -*s* and third person singular -*s* inflections. This experiment adopted an online simulation paradigm as per experiment 1 to allow for experimental testing of the theories: typically-developing children completed a word monitoring task under conditions of cognitive stress that mapped on to each of the three domains: Long sentences assessed the phonological short term memory account; noise masks (multi-talker babble and signal-correlated pink noise) tested the speech-in-noise account and a speed compression assessed the speed of information processing account. The regular plural and third person singular inflections were matched with regards to phonological saliency.

With regards to hypotheses for this experiment, the likely direction of results was two-tailed. No study has matched the phonological saliency of the third person singular and regular plural inflections, and so there was no literature upon which to base the predictions. On the one hand, the results may still have shown a noun-verb discrepancy in the cognitive stress conditions, such that sensitivity to the third person singular inflection would become impaired and the regular plural would remain robust. This would contradict the Surface Hypothesis that argues it is the phonological saliency of the inflections that explains the hierarchy of difficulty that is so apparent in the grammar of children with SLI. On the other hand, the results may have supported the Surface Hypothesis, and show that when phonological saliency is controlled between the two word classes, impairments are no longer evident.

A second prediction pertained to the varying types of cognitive stress. This study used three stressors: speed, length and noise. These placed stress on the speed of information processing, phonological short term memory and auditory perception cognitive systems respectively. In view of the uncertainty outlined above with regards to the inflection comparisons, it was unclear whether any cognitive stressor would induce SLI-like grammatical impairments. If impairments did become evident in the cognitive stress conditions, it was predicted that all three stressors would produce a similar effect. This prediction stems from the bank of literature demonstrating that very specific patterns of grammatical difficulty can be 'induced' in typically-developing participants when language processing is performed under various types of cognitive stress (not just speed), including all three under investigation in this experiment (e.g. Dick et al., 2001; Hayiou-Thomas et al., 2004; Kilborn, 1991; Witherstone, 2010).

4.2. Method

4.2.1. Participants. A total of 108 children were recruited across two North Yorkshire primary schools. All participants were native monolingual English speakers and had no history of speech, language, learning or hearing difficulties, as reported by their school teacher. Both school and parental consent was gained for each child prior to any testing.

Children in experiment 1 had an age range of 5-7 years. However, the reaction time data from the word monitoring task was skewed and had many outliers. In addition, many children found the experiment as a whole quite demanding, and attention often drifted. For these reasons, the age range of this experiment was been increased to 7-9 years.

Children were randomly allocated to one of the five cognitive stress conditions: 1) Control 2) 30% speed compressed 3) length 4) multi-talker babble noise 5) signal-correlated pink noise.

4.2.1.1 Initial screening. All children whose parents consented completed various language, nonverbal and attention measures, as detailed in chapter 2. Children were required to achieve age-appropriate scores on all of the measures to complete the experimental part of the study. Eight children were excluded as they failed to meet this requirement, leaving a total N for this study of 100. The details of the test battery scores and group allocations are outlined in table 8. A series of one-way ANOVAs showed that all five cognitive stress conditions were comparable with regards to age, gender and test battery scores (all $p>.05$).

Chapter 2 outlines all of the standardised tests in detail.

Group	N	Mean age in months (SD)	% female	BPVS-3 (/168)	TROG-2 (/80)	WISC-IV Block Design (/68)	TEA-Ch Map Mission (/80)	TEA-Ch Walk-Don't walk (/20)	Basic auditory RT in ms (SD)
Baseline	21	102.71 (6.52)	47.61	90.81	73.90	30	37.61	9.71	420 (120)
Signal-correlated noise	20	100.90 (6.01)	55	91.70	73.80	30.35	37.15	8.65	423 (149)
Multi-talker babble noise	19	101.10 (4.07)	57.89	89.58	72.42	28.11	34.11	9.16	386 (155)
30% compress	20	101.10 (6.95)	50	88.80	73.25	34.55	37.65	10.65	396 (163)
Long sentences	20	102.20 (6.92)	60	88.30	73.35	32.75	39.60	9.05	452 (162)
Total	100	101.62 (6.14)	52	89.85	73.36	31.61	37.36	9.45	414 (150)
ANOVA	*N/A*	*F(4,99)=.34, p>.05*	*N/A*	*F(4,99)=.86, p>.05*	*F(4,99)=.81, p>.05*	*F(4,99)=1.93, p>.05*	*F(4,99)=2.08, p>.05*	*F(4,99)=.95, p>.05*	*F(4,99)=1.16, p>.05*

Table 8. Mean raw scores for each standardised test, as a function of group allocation. ANOVA row refers to one-way ANOVAs with group as the independent variable and the various standardised tests as the dependent variable (exp 2)

4.2.2. Experimental Stimuli - Baseline condition. The regular plural *-s* and the third person singular *-s* inflections were the focus of this study. A stimulus set was created that contained 40 sentences – 20 assessing awareness of the regular plural inflection and 20 assessing awareness of the third person singular inflection. For each inflection, half of the sentences (10) were grammatical, whilst the other half were ungrammatical (10), such that that a bare stem was presented in place of an obligatory inflected form (e.g. *yesterday the boy **walk** to school with his friends*). Two versions of the stimulus set were created to counterbalance for grammaticality; sentences that were grammatical in set A were ungrammatical in set B and vice-versa.

As with all experiments in this thesis, a word monitoring task was used to assess inflectional awareness (see section 2.1 for information). To control for phonological confounds as discussed in section 3.4, sentences were paired, having the same critical word to independently assess the verb and noun inflections. That is, each critical word was a homophone, such that it represented either a verb or noun, depending on the sentence content. For example, the critical word /train/ was used as both a noun (*there were three trains chugging along the railway*) and a verb (*the man trains children to play football*) to assess awareness of the regular plural and third person singular inflections respectively. This resulted in 40 sentences, but 20 unique critical words. In addition, the initial phoneme sound of the target word that immediately preceded the critical word was always the same for each pair (e.g. /*trains **ch**ugging/; /trains **ch**ildren/*). This was an attempt to control for co-articulation; the co-articulation between /*train**s** **ch**ugging/* should be the same as /*train**s** **ch**ildren/*). Appendix A details all of the stimuli items.

To further control for phonological confounds, analyses were conducted to assess the amplitude and duration of the two inflections. The descriptive statistics can be seen in table 10. Paired-samples t-tests revealed no significant differences between the two word classes with regards to the inflections' amplitudes in decibels ($t(38)=.44, p>.05$) and durations in ms ($t(38)=1.66, p>.05$). This provided even more certainty that the two inflections in this study were matched with regards to their phonological features, as far as was practically possible.

Word class (inflection)	Amplitude (dB) (SD)	Duration (ms) (SD)
Noun (plural)	5.860(2.536)	0.198 (0.069)
Verb (third person)	5.467 (2.336)	0.161 (0.054)

Table 9. Mean amplitude and duration of the plural -*s* and verb -*s* (exp 2)

All sentences were controlled for on the basis of length and the number of syllables before the target word. Target words were controlled for on the basis of phonological neighbourhood density, number of phonemes and frequency (as defined by the CPWD). The details of these controls can be found in table 10. Sentences were in the active voice and of simple construction, generally assuming subject-verb-object order. Plurality was conveyed by a single digit preceding the critical noun, and tense was conveyed by a time phrase (*every day, every week etc.)* All critical words were monosyllabic, and it was ensured that no words within each sentence were acoustically similar to the target to limit the possibility of false alarm responses.

Word Class	**Mean number of syllables per sentence (SD)**	**Mean number of syllables prior to target (SD)**	**Mean frequency of target word (SD)**	**Mean phonological neighbourhood density of target (SD)**	**Mean number of phonemes in target (SD)**
Noun	11.25 (1.94)	5.15 (1.39)	263.85 (498.02)	3.05 (3.02)	4.95 (0.76)
Verb	11.05 (2.46)	4.6 (0.99)	314.75 (351.78)	4.9 (5.82)	4.4 (0.75)
Total	*11.15 (2.19)*	*4.86 (1.22)*	*351.78 (4.26)*	*5.82 (4.67)*	*0.75 (0.80)*
noun-verb paired t-test	*t(19)=.31,p>.05*	*t(19)=1.72,p>.05*	*t(19)=.36,p>.05*	*t(19)=.1.46,p>.05*	*t(19)=-1.60,p>.05*

Table 10. Details of the controls made for the target words in the sentences, as a function of the critical words' class (exp 2)

The word class frequency of the critical words was also controlled, as far as practically possible. As the critical words were the same across word classes, control of features such as length and number of syllables was irrelevant. Given that the critical words were homophones, any frequency data derived from frequency databases would be inaccurate as such databases do not distinguish between word classes (*word class frequency*). For example, it is undetermined in frequency databases whether the given frequency count for the word *watch* is for the noun version, the verb version, or both. It was important to control for this however as reaction times to the target words may have been influenced by the preceding word's basic frequency (cf. Leonard, Davis & Deevy, 2007), and that may well have extended to word class frequency. For instance, upon hearing the word /run/, it is probable that one is more likely to think of it in the verb context (*I can run*) than the noun (*I am going for a run*). As such, reaction times to a target word following /run/ is likely to be slower when it is used as a noun than a verb, as it is less frequently used in that context.

A pilot study was conducted to attempt to control for the word class frequency of the critical words in this experiment. In this pilot study, adult participants (N=10) were given each of the 20 critical words used in this experiment and asked to use it in a sentence with the first meaning that came to mind. This allowed some insight into whether the critical word was more likely to be thought of in a noun or verb context. When looking at the stimulus set as a whole, there was an even word class split. That is, the critical words were used as nouns 54% of the time, and verbs 46% of the time. This difference was not significant ($t(19)=-1.17$, $p>.05$). There were some critical words that were almost exclusively used as nouns or verbs in the pilot study, but the overall picture was even. Consequently, the critical words were controlled for on the basis of word class frequency as far as practically possible.

The tight controls that were implemented for the sentences as a whole, and the critical and target words within the sentences, helped to eliminate confounding influences on the results. It was hoped that with these controls in place, any significant findings could be attributed to the experimental manipulation, rather than extraneous variables.

In addition to responding to the target word for each sentence, participants were required to answer a comprehension question at the end of each utterance (all questions are detailed in Appendix A). The inclusion of the comprehension question stems from section 3.4, which highlighted the uncertainty around children's strategies in the word monitoring task: It was unclear whether children were *just* listening for the target and ignoring the sentence context, or whether they were processing the whole sentence when performing the word monitoring task. Scores on comprehension questions should help to shed some light on this question.

4.2.3. Recording and editing of the stimuli. The target words, associated sentences and comprehension questions were recorded by the experimenter (native English speaker) in a sound-proof room at a sample rate of 44100Hz. Full details of the recording procedure can be found in chapter 2. Sentences were spoken at a steady rate, with a mean of 182 words per minute (an 'average' conversational rate as defined by Pimsleur et al., 1977 in Tauroza & Allison, 1990).

There were four experimental cognitive stressors in this experiment: speed, multi-talker babble noise, signal-correlated noise, and length. All four stressors manipulated the baseline stimuli that has just been discussed. The creation of the four stressors and the accompanying baseline sentence manipulation will be discussed next.

4.2.3.1 Speed stressor. Sentence presentation rate was compressed by 30%, as this speed most accurately simulated an SLI-like profile of inflectional impairment in typically-developing children in experiment 1. For this manipulation, sentences were imported into PRAAT (Boersma, 2001). The speed was then compressed by 30%, in the same manner as experiment 1. This function changed the temporal profile of the sentence, but maintained the spectral characteristics to ensure that any findings would be due to the speed change, and not changes in the overall acoustic profile of the sentence.

4.2.3.2 Multi-talker babble noise. For the multi-talker babble noise mask, an adult participant was asked to talk passionately about a topic of their choice for 90 seconds in a soundproof room. Their speech was recorded by a microphone that was linked to Audacity. By talking passionately, it was hoped that a more intonated, conversational tone would be achieved. In total, speech from six adults was recorded individually – three females and three males (mean age 29years). The six individual sound files were then overlaid using Audacity, such that all six speech samples were presented at the same time. This produced a 90-second babble sound file akin to 'cafeteria noise'. No individual talker or words could be detected from the babble sound file. A random section of the babble sound file was then placed over each stimuli sentence (a different babble section for each sentence) at a constant (not fluctuating) rate of 0dB signal-to-noise ratio (cf. Ziegler et al., 2005; 2011).

4.2.3.3 Signal-correlated noise. Signal-correlated noise was created using a coding script for PRAAT (coding script available at http://www.holgermitterer.eu/research.html, script in Appendix B).

To create the signal-correlated noise, each stimuli sentence sound file was imported into PRAAT and signal-correlated pink noise was generated based on each sentence's spectrograph. Once the signal-correlated noise had been generated from the sound file, it was placed over the stimuli sentence using Audacity so as to 'mask' it at a 0dB signal-to-noise ratio (cf. Ziegler et al., 2005; 2011). This resulted in the sentence being masked with pink noise that followed the acoustic profile of the underlying speech (i.e. stronger noise mask for the more acoustically-salient parts of the sentence; weaker noise mask for the less salient aspects). This was thought to ensure that the inflections within a sentence were not 'unfairly' masked (see section 4.4 for a discussion on this).

4.2.3.4 Length stressor. For the length stressor, redundant filler words were inserted prior to the critical word in each sentence, so as to place added constraints on verbal working memory systems (cf. Hayiou-Thomas et al., 2004; Witherstone, 2010). It was always ensured that the phrases in which the critical and target words occurred (i.e. the verb phrase for the third person singular sentences and the noun phrase for the plural sentences) were not changed. This meant that the length of the sentence was altered, but the syntactic complexity of the sentences was preserved as far as possible. For instance, the sentence *'the man draws fish whilst sitting by the pond'* became *'the old grey-haired man draws fish whilst sitting by the pond'*. This is in contrast to lengthening the sentence to *'the man carefully and quietly draws fish whilst sitting by the pond'* for example, which would both lengthen the sentence and increase the syntactic complexity as the verb phrase would be altered. Generally speaking, the verb sentences involved adding adjectives to describe the subject of the sentence. The noun sentences added a prepositional phrase at the beginning of the construction. Appendix A lists all stimuli. The additional words increased the number of syllables prior to the target by approximately 50% (in-line with Hayiou-Thomas et al., 2004 and Witherstone, 2010) for each sentence. These new, longer sentences were recorded in the same manner as the baseline stimuli. The long sentences were spoken at an average of 181 words per minute (an 'average' conversational rate as defined by Pimsleur et al., 1977 in Tauroza & Allison, 1990). Long sentences were not spoken significantly faster than baseline sentences ($t(19)=-6.41$,p>.05)).

Table 11 shows the descriptive statistics for the baseline and long sentences. Paired-samples t-tests revealed that the target in the 'long' sentences did indeed occur after more syllables than the control sentences for both the noun ($t(19)=-9.72$, $p>.05$) and verb ($t(19)=-8.54$, $p>.05$) items. Analyses also showed that the target in the 'long' sentences occurred after more time (in ms) than the control sentences for both the noun ($t(19)=-9.45$, $p>.05$) and verb items ($t(19)=-9.48$,$p>.05$).

	Number of syllables before target (SD)		**Position of target in milliseconds (SD)**	
	Baseline	**Long**	**Baseline**	**Long**
Noun	5.15 (1.39)	8.85 (1.46)	518 (41)	653 (35)
Verb	4.6 (0.99)	8.20 (1.54)	500 (26)	630 (69)
Total	*4.86 (1.19)*	*8.53 (1.5)*	*509 (34)*	*641 (52)*

Table 11. Comparing the features of the baseline and long sentences, as a function of word class (exp 2)

4.2.4. Intelligibility of stimuli. It is important to note that the first instance of the target word for each sentence was always presented under normal conditions (i.e. no stressor) to ensure maximum auditory perception; only the sentence containing the target word was manipulated for cognitive stress (see chapter 2 for full details). In addition, it was crucial to ensure that the sentences were intelligible, even when the cognitive stressors had been introduced. This is so any results can be attributed to the experimental manipulation, rather than intelligibility confounds. Twenty percent of the stimuli items (total of 8 sentences, half grammatical, half ungrammatical) for each condition (control, 30% time compressed, signal-correlated noise, multi-talker babble noise, long sentences) were presented to 10 adult participants. The participants were instructed to repeat the sentence verbatim, including any potential grammatical mistakes. Accuracy rates were very reassuring: Sentences were repeated verbatim with 100% accuracy in both the baseline and long conditions, 96% in the 30% speeded condition, 97% in the signal-correlated noise condition and 94% in the multi-talker babble noise condition.

4.2.5. Presentation of stimuli. In total, there were 10 stimulus sets, each containing 40 sentences (20 per inflection, half grammatical, half ungrammatical): Control, 30% compressed, signal-correlated noise, multi-talker babble noise, and long sentences. Each of these had A and B versions that were counterbalanced for grammaticality.

The task was presented in the standard way for this thesis, as outlined in chapter 2. A simple comprehension question was added 1.5seconds after each sentence; a full stimuli list can be found in Appendix A.

4.2.6. Design. Cognitive stressor (baseline, 30% compressed, signal-correlated noise, multi-talker babble noise, long sentences) was an independent-groups variable. Grammaticality (grammatical, ungrammatical) and inflection type (third person singular, regular plural) were repeated-measures variables. Therefore, any given child heard 40 sentences (20 per inflection, half grammatical and half ungrammatical) under one type of cognitive stress.

4.2.7. Procedure. Children were visited in their school during normal teaching hours for one testing session, lasting approximately one and-a-half hours in total. Within this testing session, children completed all standardised measures first, before having a 30-minute break (the experimenter used this time to score the standardised tests in order to determine if the child reached age-appropriate levels). If the children were identified as being typically-developing, they then completed the basic auditory reaction time task and the word monitoring task (all are detailed in chapter 2). A comprehension question was asked after each sentence in the word monitoring task. The basic auditory reaction time task was always carried out before the word monitoring task in order to give children practice with a fast-response task, and to increase intraparticipant reaction time stability (cf. Montgomery & Leonard, 2006).

4.3. Results

4.3.1. Data preparation. Participant reaction times to the target words were calculated in the same manner as experiment 1 (see section 3.3.1 for details). Also analogous to experiment 1, false data points and non-responses were removed and replaced with the mean for that word class and grammaticality (see section 3.3.1 for details). Finally, reaction time data were log-transformed due to skew, as recommended by Ratcliff (1993). All reaction time analyses for this experiment are based upon log-transformed data, unless otherwise stated.

4.3.2. Word monitoring task

4.3.2.1 Accuracy. There were no instances of non-responses for this task; all children pressed the response key for every trial. All responses that occurred before the target word were classified as 'false alarms'. These were removed from the data set, and were replaced by the mean score based on all valid data points for that grammaticality and word class (as per the procedure detailed in section 3.3.1). Overall, 1.79% of data points were removed on the basis of being false alarms, and so accuracy on the whole was excellent. An independent-samples t-test revealed no effect of sentence set (A or B) upon accuracy rates ($t(92)=.73$, $p>.05$), and so all statistical analyses were collapsed across the two sentence sets.

Table 12 details the error rate (false alarm) scores (raw scores, out of a maximum of 40 sentences) for this experiment, separated by cognitive stress condition. A one-way ANOVA was conducted on the error data, with group as the independent variable and number of errors as the dependent variable. Results showed that there was no main effect of group ($F(4,99)=.93, p>.05$), suggesting accuracy levels were similar across all five cognitive stress conditions. It is pertinent to note that there was a slight trend for accuracy to decrease when cognitive stress was introduced, especially with regards to the 30% speeded and multi-talker babble conditions.

Table 12. Mean number of errors (false alarms) made for each of the five conditions. Maximum error rate = 40. (exp 2)

Group	**Number of errors (SD)**
Baseline	1.857 (1.905)
30% speed compressed	3.400 (1.875)
Long sentences	2.368 (1.461)
Multi-talker babble noise mask	3.300 (3.011)
Signal-correlated noise mask	2.860 (3.333)

A bivariate Pearson's correlation was conducted to assess whether there was a speed-accuracy trade-off. That is, were children more likely to make errors when they responded quickly? Data were collapsed across cognitive stress condition because the analysis above showed this not to affect error rates. Results indicate that there was no speed-accuracy trade-off: there was no significant relationship between reaction times in the word monitoring task (mean 620.593ms, SD 972.20ms) and the number of errors made (mean error rate 2.860, SD 3.33) ($r=-.117$, $p>.05$). This suggests that even when children responded quickly, they remained accurate.

4.3.2.2 Grammatical Sensitivity. The overall mean reaction times to the target words are presented in table 13, collapsed across word class and grammaticality (both raw and log-transformed data are presented for transparency). A one-way ANOVA showed no main effect of cognitive stressor upon overall log-transformed reaction times ($F(4,99)=.71, p>.05$). This suggests that reaction times as a whole were similar across the various conditions in this experiment. What is of more interest to this study however is how the various cognitive stressors affect sensitivity to grammaticality; that is, were children less sensitive to the grammaticality of a sentence when they were listening to language under conditions of cognitive stress, as compared to optimum (silent, baseline) listening conditions?

A 5 (cognitive stressor group: baseline, signal-correlated noise, multi-talker babble noise, 30% speed compression, long sentences) x 2 (grammaticality: grammatical, ungrammatical) x 2 (inflection: third person singular, regular plural) repeated-measures ANOVA was conducted on the log-transformed data. There were significant main effects of grammaticality ($F(1,95)=66.37, p<.001$) and inflection ($F(1,95)=6.65, p=.011$). Table 14 shows that grammatical sentences were generally responded to faster than ungrammatical, and that targets following a noun were usually responded to faster than targets following a verb. These two main effects mirror the standard word monitoring finding (cf. Montgomery & Leonard, 2006).

In addition, there were significant interactions between inflection and group ($F(1,95)=3.13, p=.018$) and grammaticality and group ($F(1,95)=8.11, p<.001$). Finally, the three-way interaction between grammaticality, inflection and group was approaching significance ($F(1,95)=4.65, p=.051$). The interaction between inflection and grammaticality was non-significant ($F(1,95)=1.62, p>.05$). Due to the complex nature of the results, and because of the specific hypotheses, each cognitive stressor will be examined individually.

Table 13. Mean raw and log-transformed reaction times for each of the five conditions, collapsed across grammaticality and inflection (exp 2)

Cognitive stressor	Mean raw RT (and SD)	Mean log-transformed RT (and SD)
Baseline	586 (180)	2.75 (2.25)
Signal-correlated noise	484 (91)	2.68 (1.96)
Multi-talker babble noise	473 (71)	2.67 (1.85)
30% speed compressed	928 (132)	2.97 (2.12)
Long sentences	623 (230)	2.78 (2.36)

Table 14. Mean raw reaction times (and standard deviations) in milliseconds in the word monitoring task, as a function of group, grammaticality and word class *(NB: Log-transformed data will be presented in the graphs to follow)* (exp 2)

	Noun		**Verb**	
	Grammatical	**Ungrammatical**	**Grammatical**	**Ungrammatical**
Baseline	371 (234)	763 (245)	417 (224)	796 (229)
30% speed compressed	823 (108)	1089 (209)	836 (175)	968 (254)
Long sentences	496 (232)	636 (415)	612 (620)	749 (417)
Multi-talker babble	410 (79)	495 (84)	464 (97)	525 (81)
Signal-correlated noise	432 (148)	481 (102)	478 (130)	548 (129)

4.3.2.2.1. Baseline effect. A 2 (grammaticality: grammatical, ungrammatical) x 2 (inflection: third person singular, regular plural) repeated measures ANOVA was conducted on the log-transformed data from the baseline condition. Results showed the standard word monitoring task effect. That is, there was a main effect of grammaticality ($F(1,20)=50.26$, $p<.001$), such that target words following a grammatical critical word were responded to more quickly (mean raw reaction time 394ms, raw SD 227ms; mean log reaction time 2.56ms, log SD 2.37ms) than ungrammatical constructions (mean raw reaction time 779ms, SD 234ms; mean log reaction time 2.89ms, log SD 2.37ms). This suggests children were sensitive to the grammaticality for all sentences in this baseline condition.

There was also a significant main effect of inflection type ($F(1,20)=4.81$, $p=.040$), such that target words following a noun (plural inflection) were responded to more quickly (mean raw reaction time 567ms, SD 239ms; mean log reaction time 2.75ms, log SD 2.38ms) than words following a verb (third person singular inflection) (mean raw reaction time 606ms, SD 226ms; mean log reaction time 2.78, log SD 2.35ms). There was no significant grammaticality*inflection interaction ($F(1,20)=1.96$, $p>.05$). These results can be seen graphically in figure 9.

4.3.2.2.2. *Signal-correlated noise.* A 2 (grammaticality: grammatical, ungrammatical) x 2 (inflection: third person singular, regular plural) repeated measures ANOVA was conducted on the log-transformed data from the signal-correlated noise condition. The results showed significant main effects of grammaticality, such that targets following a grammatical word were responded to faster (mean raw RT 455ms, SD 138ms, log RT 2.66ms, SD 2.14ms) than those following ungrammatical words (mean raw RT 514ms, SD 115ms, log RT 2.71ms, SD 2.06ms) ($F(1,19)=7.74, p=.012$). There was a significant effect of inflection type, such that targets following a noun item were responded to faster (mean raw RT 456ms, SD 124ms, log RT 2.66ms, SD 2.09ms) than targets following a third person singular item (mean raw RT 512ms, SD 129ms, log RT 2.71ms, SD 2.11ms) ($F(1,19)=8.94, p=.008$). There was a non-significant grammaticality*inflection interaction ($F(1,19)=.04, p>.05$). These results mimic the baseline effect: grammatical sentences were responded to faster than ungrammatical sentences and target words following nouns were responded to more quickly than targets following verbs. The results are represented graphically in figure 9.

4.3.2.2.3. Multi-talker babble noise. A 2 (grammaticality: grammatical, ungrammatical) x 2 (inflection: third person singular, regular plural) repeated measures ANOVA was conducted on the log-transformed data from the multi-talker babble noise condition. The results showed a significant main effect of grammaticality, such that targets following a grammatical word were responded to faster (mean raw RT 436ms, SD 88.32ms, log RT 2.64ms, SD 1.94ms) than those following ungrammatical words (mean raw RT 510ms, SD 82.78ms, log RT 2.71ms, SD 1.92ms) ($F(1,18)=29.19, p<.001$). There was a significant effect of inflection type, such that targets following a noun item were responded to faster (mean raw RT 452ms, SD 81ms, log RT 2.66ms, SD 1.91ms) than targets following a third person singular item (mean raw RT 494ms, SD 89ms, log RT 2.69ms, SD 1.95ms) ($F(1,18)=11.76, p.003$). There was a non-significant grammaticality*inflection interaction ($F(1,18)=1.54, p>.05$). These results mimic the baseline effect, and that of the signal-correlated noise condition: grammatical sentences were responded to faster than ungrammatical sentences and target words following nouns were responded to more quickly than targets following verbs. The results are represented graphically in figure 9.

4.3.2.2.4. Speed stressor. A 2 (grammaticality: grammatical, ungrammatical) x 2 (inflection: third person singular, regular plural) repeated measures ANOVA was conducted on the log-transformed data from the 30% speed condition. The results showed a main effect of grammaticality, such that targets following a grammatical word were responded to faster (mean raw RT 829ms, SD 141ms, log RT 2.92ms, SD 2.15ms) than those following ungrammatical words (mean raw RT 1028ms, SD 231ms, log RT 3.01ms, SD 2.36ms) ($F(1,19)=21.50, p<.001$). There was a non-significant effect of inflection (mean raw noun RT 954ms, SD 159ms log RT 2.98ms, SD 2.20ms; mean raw third person RT 902ms, SD 214ms, log RT 2.96ms, SD 2.33ms) ($F(1,19)=.07, p>.05$). However, there was a significant interaction between grammaticality and inflection ($F(1,19)=5.75, p=.041$). This can be seen graphically in figure 9. The figure suggests that whilst children were still sensitive to grammaticality in the noun sentences when stimuli were speeded (i.e. there is a large gap between the bars, indicating that they are responding very differently to grammatical, versus ungrammatical, sentences), they became less sensitive to the grammaticality in the verbs. This replicates what was seen in experiment 1, albeit to a less severe degree.

4.3.2.2.5. Length stressor. A 2 (grammaticality: grammatical, ungrammatical) x 2 (inflection: third person singular, regular plural) repeated measures ANOVA was conducted on the log-transformed data from the long sentences condition. The results showed significant main effects of grammaticality, such that targets following a grammatical word were responded to faster (mean raw RT 554ms, SD 426ms, log RT 2.74ms, SD 2.63ms) than those following ungrammatical words (mean raw RT 692ms, SD 415ms, log RT 2.84ms, SD 2.62ms) ($F(1,19)=17.48, p=.001$). There was a main effect of inflection , such that targets following a noun item were responded to faster (mean raw RT 565ms, SD 323ms, log RT 2.75ms, SD 2.51ms) than targets following a third person singular item (mean raw RT 680ms, SD 545ms, log RT 2.83ms, SD 2.74ms) ($F(1,19)=11.05, p=.004$). There was a non-significant grammaticality*inflection interaction ($F(1,19)=2.35, p>.05$). These results mimic the baseline effect, and that of the both noise mask conditions: grammatical sentences were responded to faster than ungrammatical sentences and target words following nouns were responded to more quickly than targets following verbs. The results are represented graphically in figure 9.

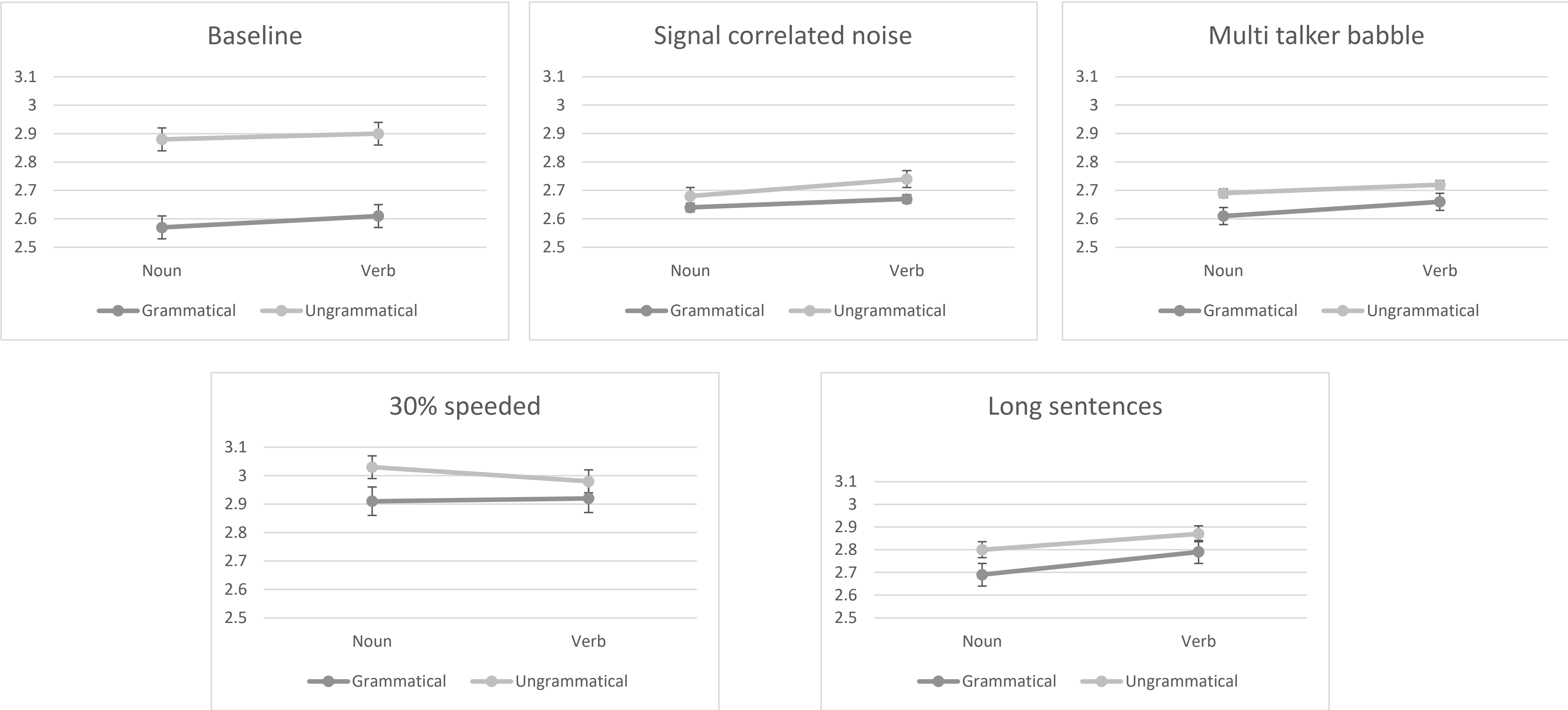


Figure 9. Mean log transformed reaction times to target words in the word monitoring task, separated by inflection type and grammaticality. Error bars represent standard error (exp 2)

4.3.2.2.6. Comparisons between stressors and baseline. When comparing the data from the several conditions, it can be seen that overall reaction times get faster in the cognitive stress conditions, as compared to the baseline condition. It can also be seen that on the whole, sensitivity to grammaticality seems to reduce in the cognitive stress conditions, as compared to baseline. This is indicated by the magnitude of the distance between the bars for each inflection. At baseline, the bars are far apart for each inflection, indicating a large difference in reaction times between grammatical and ungrammatical constructions. In all of the experimental conditions, the bars appear to move closer together, reflecting more similar reaction times for grammatical and ungrammatical constructions (and therefore less sensitivity to grammaticality.

This pattern of reduced grammatical sensitivity is a little different in the 30% speeded condition, where it can be seen that the speed stressor does not seem to reduce the size (relative to baseline) of the distance between the bars for the noun items, but it does quite significantly for the verb items. This suggests that sensitivity to noun (plural) grammaticality is relatively unaffected by the speed stressor, but sensitivity to verb (third-person) grammaticality *is* affected. It can also be seen that the speed stressor does not affect reaction times to the ungrammatical constructions as much as the other stressors do, as compared to the baseline condition.

4.3.2.2.7. Assessing the contribution of basic auditory RT. Given that the dependent variable in the word monitoring task was reaction time, it may be useful to assess the effects of the cognitive stressors once basic auditory reaction time has been taken into account. This would presumably leave a 'purer' linguistic measure of grammatical sensitivity in the word monitoring task. As the basic auditory reaction times did not differ between the five groups, it was not considered to be of utmost importance to control for this when conducting the main analyses detailed previously. Nevertheless, a series of 2 (grammaticality: grammatical, ungrammatical) x 2 (inflection: plurals, third person singular) one-way repeated-measures ANOVAs were conducted for each of the five cognitive stress conditions, being sure to enter 'basic auditory reaction time' as a covariate in the analyses.

Although the effects were weaker, the same general pattern emerged: There were main effects of grammaticality and inflection for the baseline (grammaticality: $F(1,19)=5.08$, $p=.036$; inflection: $F(1,19)=11.41$, $p=.003$), multi-talker babble noise (grammaticality: $F(1,19)=5.65$, $p=.029$; inflection: $F(1,19)=5.39$, $p=.033$) and long sentences (grammaticality: $F(1,19)=6.33$, $p=.022$; inflection: $F(1,19)=4.26$, $p=.054$). The main effects were just out of significance for the signal-correlated noise condition (grammaticality: $F(1,19)=3.79$, $p=.067$; inflection: $F(1,19)=3.39$, $p=.062$). In addition, the pattern found for the 30% speed compressed condition replicated what was found in the main analyses: (grammaticality: $F(1,19)=4.55$, $p=.047$; inflection: $F(1,19)=2.53$, $p>.05$; grammaticality*inflection $F(1,19)=4.79$, $p=.042$).

4.4. Discussion

This experiment had two main purposes: The first purpose was to assess and compare the effect of various different cognitive stressors upon online inflectional processing. Secondly, this experiment set out to examine two phonologically-matched inflections.

This section will first discuss the cognitive stressors used in this experiment. It will then explore the comparisons between the two inflections. Finally, the theoretical implications and future directions raised by the findings of this experiment will be discussed.

4.4.1. Is speed special? Experiment 1 found that speeding sentences up by 30% led typically-developing children to demonstrate SLI-like grammatical impairments, as measured by an online word monitoring task. That is, verb morphology seemed to become impaired whilst noun morphology remained robust in the face of cognitive stress. Section 3.4 highlighted that, as speed was the only cognitive stressor used in the experiment, it was unclear whether speeding sentences was ‘key’ to inducing grammatical impairments or whether *any* cognitive stressor would be sufficient. For this reason, this experiment used several cognitive stressors: 30% speed compression for replication purposes, signal-correlated noise mask, multi-talker babble noise mask and long sentences. These stressors placed stress on the Speed of Information Processing, Auditory Processing and

Phonological Short Term Memory cognitive domains respectively. A no-stress, baseline condition also featured in this study.

When comparing the four stressors to the baseline condition, an overall pattern of grammatical impairment was apparent. The word monitoring task compares the reaction times to target words following grammatical and ungrammatical constructions; a significant difference in these two reaction times implies some level of processing of the inflection (e.g. Tyler, 1992). Conversely, a non-significant difference in reaction times suggests that children are not processing the grammaticality of the sentences, and are regarding both grammatical and ungrammatical constructions as 'equal'. When we look at the baseline condition, it can be seen that there are large gaps between the 'grammatical' and 'ungrammatical' lines on the graph. This represents inflectional processing, or sensitivity. That is, the grammatical and ungrammatical sentences were responded to differentially. When we look at the four cognitive stress conditions, we still see a gap between the lines, but this gap is much smaller than we see in the baseline condition. This smaller gap represents a weakened sensitivity to the grammaticality within the sentences.

For the baseline, the two noise mask conditions and the long sentence condition, there was no grammaticality*inflection interaction. This means that sensitivity to grammaticality was the same for both the noun and verb inflections. However, in the 30% speeded condition there was an interaction, which manifested itself as an SLI-like deficit. That is, sensitivity to noun (plural) grammaticality remained intact, but sensitivity to verb (third person singular) became impaired, as evidenced by a much smaller gap between the lines on the graph. This replicated the findings of experiment 1, and suggests that there is indeed something 'special' about stressing speed of processing, rather than just general cognitive stress. This has theoretical implications with regards to the aetiology of SLI: It is becoming more apparent that the inflectional difficulties experienced by children with SLI may be mediated by a deficit in speed of information processing specifically, rather than a general cognitive deficit.

The findings discussed here were still evident, even when basic auditory reaction time was taken into account. The word monitoring task is based upon reaction times, and by using basic auditory reaction time as a covariate, we were able gauge whether the effects were still present after individual response speed was accounted for. That is, by entering basic reaction time as a covariate, we would presumably be left with a much 'purer' linguistic measure in the word monitoring task. Even when taking basic auditory reaction time into account, it was still only the speed stressor that induced the SLI-like profile of inflectional impairment in the typically-developing participants.

4.4.2. What makes speed special? How exactly can a problem with processing language in a time-efficient manner explain deficits in verb morphology, but not noun morphology?

In everyday speech, the third person singular -*s* is less salient than the regular plural -*s*. It is not only weaker in amplitude, but is shorter in duration (see Black & Chiat, 2003 for a review). This means that it is likely to be more time-dependent than the noun. Although the phonemes were controlled in this study (i.e. verbs and nouns were 'matched' to control for duration and amplitude, and the co-articulation between the critical and target words were the same between word classes), they are not controlled in the real-world. The disadvantage may have already 'done its work' and led to a weaker representation for the verb morphology. Consequently, this morpheme may be more susceptible to stress, as its lexical representation is potentially weaker and more contingent upon temporal properties than the noun morpheme is.

Although this seems like a plausible explanation, it cannot explain all of the results in this experiment. Whilst verb morphology is indeed *shorter in duration* than noun morphology in everyday language (and thus making possibly making it more susceptible to a speed stressor than plural items), it is also *quieter in amplitude.* By this line of reasoning then, one would expect the noise masks to also disadvantage awareness of the verb morphology, but not the noun morphology. However, this was not the case. Neither the signal-correlated noise mask, or the multi-talker babble noise mask, resulted in an SLI-like profile of inflectional impairment. Both masks did detriment overall grammatical sensitivity (as evidenced by a smaller gap between the grammatical and ungrammatical bars), but not enough to eradicate the overall main effect of grammaticality.

Perhaps then the noise was not noisy *enough?* Indeed, the overall reaction times to the target words actually *improved* in the noise masked conditions, as compared to baseline, suggesting that the stressors were not difficult (0dB signal to noise ratio). This reaction time improvement in mildly-stressed conditions was also evident in experiment 1 (in the 10% speeded condition), and in the work of Montgomery and Leonard (1998; 2006). It has been suggested in section 3.4 and by Mongtomery and Leonard (2006) that a small amount of cognitive stress actually encourages the children to engage more with the task at hand, as it is a little more challenging and exciting than the baseline conditions. This further supports the notion that the noise masks were not noisy *enough* in this experiment; they were enough to challenge and enhance engagement, but not enough to detriment inflectional awareness. Future research could investigate varying levels of noise mask signal-to-noise ratio in order to further explore whether speed is the 'key' stressor, or whether any cognitive stress results in an SLI-like profile of inflectional impairment. The signal-to-noise ratios could be gradually decreased (i.e. get noisier), similar to what was done in experiment 1 with the speeds being gradually increased.

4.4.3. Comparing the two noise masks. This experiment used two different noise masks as stressors: A signal-correlated pink noise mask and a static multi-talker babble noise mask. There were several reasons for including the two types of noise mask. Firstly, there has been much research conducted that uses a static pink noise mask (e.g. Kilborn, 1991; Ziegler et al., 2005, 2011). Because speech is naturally-fluctuating with regards to amplitude, and because inflections are some of the phonologically-weakest parts of a sentence, static noise masks will mask the underlying sentence with differing relative intensities. That is, the phonologically-weaker parts of a sentence will suffer more relative masking than the stronger parts. This is especially important to consider, given that inflections are often the weakest parts. As such, inflections may be 'unfairly' masked, or be at a ‘masking disadvantage’. For this reason, a signal-correlated mask was used. Signal-correlated masks are fluctuating in amplitude, in accordance with the speech that they are masking: The phonologically-weaker parts of the sentence are masked with less amplitude than the phonologically-stronger parts of the sentence. This leads to a much ‘fairer’ noise mask: it gives the inflections a chance to be heard.

Ziegler (2005, 2011) went to great lengths to explain why it is important to assess language processing in noisy environments when looking at SLI, because this represents their life on a day-to-day basis. However, he used a static pink noise in both studies. What would be more representative of a child’s day-to-day life is multi-talker babble noise. Hence, this noise mask was included in this study.

The findings of this study found no differences in inflectional awareness between the two noise masks, although there appeared to be a trend for the multi-talker babble to detriment sensitivity to grammaticality slightly more than the signal-correlated noise. This is somewhat unsurprising, given that it is composed of actual language, rather than the pink noise mask that is simply on the same spectrum as speech. Perhaps differential effects will begin to show in more difficult (i.e. noisier) conditions.

4.4.4. The length stressor. In this experiment, lengthening sentences, by means of adding in filler words before the target, did not affect sensitivity to grammaticality, as compared to baseline. In fact, the results for this condition were remarkably similar to the baseline results. Even though the two noise masks did not affect inflectional sensitivity in an SLI-like manner, they did negatively affect overall sensitivity to grammaticality, as compared to baseline. This was not the case when sentences were lengthened.

There are two possible reasons for the lack of effect in the length condition. Firstly, it may be that children are simply listening out for the target word embedded within the sentence when performing the word monitoring task, and that they are not listening to the content of the sentence. This would explain why more words did not detriment performance – they were not storing them in their phonological working memory. However, scores from the comprehension questions (see section 7.3) suggest that this is an unlikely explanation: children were very successful at answering questions about the sentence content. In addition, even if their original strategy is to first only listen for the target word, once they realise they would be asked a comprehension question children are likely to shift strategy and begin listening to the whole sentence in order to perform well on the questions.

The second possible reason for the lack of effect in the length condition is a more theoretical one, and relates to the phonological working memory system. By definition, the phonological working memory system is involved in *working* with information that is being remembered. The more work that is to be done with information, the more this memory system is challenged. Simply adding words to sentences may have only increased working memory *load*. In order to manipulate how much 'working' the phonological working memory system has to do, one could introduce a secondary task, such as a dual-attention assignment. However, this would make the word monitoring task very complex indeed, and there would be many variables to consider, such as the type of dual attention task and the motor responses needed. For instance, a common dual-attention task is some form of 'tapping' assignment, however this would confound performance in the word monitoring task as a physical button-press is required.

4.4.5. Comparing plural -*s* and third person singular -*s*. This study looked to further investigate the regular plural -*s* inflection and the third person singular -*s* inflection; they are the same phoneme but are impaired to very differing degrees in SLI. This was simulated in experiment 1, whereby stressing the Speed of Information Processing cognitive system resulted in impairment in the verb -*s* inflection but not the noun -*s*. Research was presented in section 3.4 that suggested that although the inflections are represented by the same phoneme, they may not be phonologically identical. Specifically, research has suggested that the regular plural is more phonologically salient within a sentence than the third person singular (see Black & Chiat, 2003), both with regards to amplitude and duration.

This study looked to see if the verb/noun impairment discrepancy would still be evident when the two inflections were indeed phonologically identical. The stimuli were matched in the sense that they were homophones, and the acoustic properties underwent statistical analyses to confirm that there were no significant differences in either amplitude or duration between the two word classes. This was the first study of its kind to attempt to match the phonological saliency of the morphemes in such a way, and so there was a strong novel element to this piece of research.

The current experiment found that even though the inflections were matched with regards to phonological saliency, there was still a verb/noun discrepancy when stimuli were speeded by 30%. That is, stressing speed of processing resulted in sensitivity to the third person singular inflection being reduced, but not the regular plural inflection, as compared to baseline. Neither noise mask, nor the length stressor resulted in this discrepancy. This is an interesting finding: Even when the two inflections are phonologically identical, they are *still* impaired to differing degrees when the 'right' cognitive stress is introduced. This has really important theoretical implications, particularly for the Surface Hypothesis which predicts that impaired speed of processing interacts with the phonological saliency of inflections to determine their affectedness in SLI.

So, why might verb morphology be impaired by speeding sentences, but not noun morphology? One possibility lies in the phonology. Although this study controlled for phonology, in that the two inflections were matched, the inflections in the real-world are not phonologically matched. The plural *-s* is much more phonologically-salient than the third person singular *-s*, and it is much more likely to be found in sentence-final positions, which adds to the saliency of the inflection. This increased saliency in the real-world may lead to more robust representations of the inflections. Therefore, although the phonemes were matched in this study, individuals have had their whole lives being exposed to a phonological disadvantage for the third person singular *-s*, as compared to the regular plural *-s*. This may explain why the noun morphology was not affected by the speed stressor: its representation is so much stronger than the verb morphology and so is less susceptible to stress.

Although this seems like a plausible explanation, it still does not account for the reason why speed affected awareness, but the other stressors did not. The proposals of the Surface Hypothesis are becoming more and more plausible now. Leonard and colleagues (see Leonard, 2014) argued that there was a complex interaction between speed of processing and the phonological saliency of inflections, such that those inflections that were weaker in saliency were more susceptible to damage in the face of speed of processing impairments or stress. Phonological saliency relates to not only amplitude, but also duration, and there is much research to support the finding that the third person singular inflection is shorter and quieter in everyday speech. Perhaps the reason why the speed stressor in this experiment only affected sensitivity to the third person singular inflection is, quite simply, because it is the weaker inflection in naturalistic language (resulting in weaker phonological representations). To fully test this theory, one would need to assess the phonological saliency and the affectedness of the regular past tense inflection, too. This inflection is the most impaired in SLI (see section 1.3.3), and is generally weaker in phonological saliency than both the third person singular and the regular plural inflections (see Black & Chiat, 2003), and thus even more time-dependent. If the Surface Hypothesis were true, one would expect this inflection to be the most impaired in the face of a speed stressor, but to remain robust in the face of other (non-speed) stressors.

4.4.6. Theoretical implications and future directions. This study raises some important theoretical implications. Firstly, it does seem possible that it is *speed* that is the 'key' cognitive stressor in order to simulate SLI-like grammatical impairments in typically-developing children, rather than *any* cognitive stress. Both experiment 1 and this study has found that typically-developing children become less sensitive to the grammaticality in verb morphology, but not noun morphology, when sentences are speeded by 30%. This simulation was not evident when children's phonological working term memory or auditory processing cognitive systems were stressed by means of lengthening and noise-masking sentences respectively.

However, two issues have arisen from this study: Firstly, it may have been that the noise was not 'noisy' enough. Experiment 1 carefully calibrated the speed of the sentences to establish the best level at which to simulate the grammatical impairments seen in SLI. The noise masks in this study were both placed at 0dB signal-to-noise ratio (in-line with most previous literature e.g. Kilborn, 1991; Ziegler et al., 2005; 2011). Whilst overall grammatical sensitivity was reduced in the noise-masked conditions as compared to baseline, the effect was only slight, and certainly was no selective as was the case with the 30% speed compression. Perhaps a more 'noisy' mask would begin to impair grammatical sensitivity selectively, as we seen in SLI?

Secondly, this study focussed on the two *-s* inflections – the regular plural and the third person singular. Whilst this had its merits in terms of controlling for phonological saliency, it is felt that the overall conclusions are somewhat lacking without the regular past tense inflection. Deficits in the regular past tense are very persistent in children with SLI (Bishop, 2014), and past-tense deficits are a key marker of the disorder (Conti-Ramsden, 2003). Consequently, the question stands of whether we can really say that the grammatical deficits in SLI have been simulated without demonstrating impairment in the regular past tense? The hierarchy of inflectional difficulty is so robust in populations with SLI (regular past tense most impaired, third person singular moderately impaired, regular plural unaffected), that any model of SLI should encompass all facets of this hierarchy, if it is to substantiate claims about the aetiology of the disorder. In addition, by including the regular past tense into future experiments, the Surface Hypothesis can be tested further to investigate whether it is indeed the phonological saliency of inflections that determine their affectedness (alongside impairment in speed of processing).

4.4.7. Summary and conclusions. This study compared the effect of the cognitive stressors of speed, length and noise mask (multi-talker babble and signal-correlated noise) upon the real-time inflectional processing of typically-developing children. The inflections under investigation were the third person singular *-s* and the regular plural *-s*; these were matched for phonological saliency. This study found that when sentences were speeded by 30%, typically-developing children showed SLI-like inflectional impairments. That is, sensitivity to verb morphology became impaired whilst noun morphology remained robust in the face of cognitive stress. This was not the case with the length or noise stressors. This suggests that the inflectional difficulties experienced by children with SLI may be the result of an impairment in the speed with which language can be processed, rather than a general cognitive deficit. It is possible that, because inflections are highly time-dependent (they are very brief in duration), any weakness in speed of processing results in inflections being processed less effectively.

Although the inflections in this experiment were phonologically-identical, the third person singular -*s* is much weaker in phonological saliency than the regular plural -*s* in real-world speech. This may result in weaker morphological representations which might explain the difficulties seen in both the expressive and receptive language of children with SLI, and may account for the inflections still being differentially impaired in this study, despite being 'matched'.

However, inflections are not only brief in duration, they are also quieter in amplitude. This is especially the case for the third person singular -*s*, as compared to the regular plural -*s*. In this sense then, one would have expected the noise masks to have had a detrimental and differential (verbs impaired, nouns robust) effect on the participants' inflectional processing in this study. As discussed, it may have been that the noise masks were not 'noisy' enough (i.e. they did not have a small enough signal-to-noise ratio). Future work is needed that calibrates the signal-to-noise ratio, as was the case with speed in experiment 1.

In addition, the regular past tense needs to feature in future simulation studies, as this is the hallmark deficit of SLI (Conti-Ramsden, 2003). If the grammatical impairments in SLI are to be accurately simulated, one must be able to demonstrate that the regular past tense is the most impaired inflection, as it is in the language of children with SLI. Inclusion of the regular past tense would also allow for further examination of the (phonological saliency) arguments proposed by the Surface Hypothesis.

Chapter 5. Experiment 3: Auditory Perception; Calibrating Signal-to-noise ratio

5.1. Introduction

Experiment 2 compared the effects of various cognitive stressors upon the real-time awareness of inflections in typically-developing children. The cognitive stressors used were 1) speed 2) length 3) noise mask (multi-talker babble noise and signal-correlated pink noise). The results showed that whilst all cognitive stressors had some detrimental impact upon real-time inflectional processing, it was only the speed stressor that resulted in an SLI-like pattern of inflectional impairment (nouns robust, verbs impaired). However, it was argued that the noise masks may not have been noisy enough. Experiment 2 used both noise masks at a 0dB signal-to-noise ratio, and it was suggested that an SLI-like pattern of inflectional impairment may become evident when the signal-to-noise ratio is decreased (that is, the noise mask gets louder relative to the underlying sentence, therefore making it harder to perceive the underlying speech signal). In view of this, the third experiment of this thesis set out to systematically manipulate the signal-to-noise ratio of the noise masks, in the same way that Experiment 1 of this thesis systematically manipulated the speed of the sentences.

There is some literature that has explored the effects of varying noise mask levels upon speech perception, which helps to inform the methodology of this experiment. For example, Brungart, Simpson, Ericson and Scott (2001) measured the ability of adult participants to detect a target that was masked by multi-talker babble noise, placed at varying signal-to-noise ratios. They found that the intelligibility of the target decreased with the number of talkers within the multi-talker babble noise mask. In addition, target perception rates began to fall once the signal-to-noise ratio achieved a level of approximately -3dB. Perception rates fell below 50% when the signal-to-noise ratio was around -9dB.

The current study sought to ‘calibrate’ the signal-to-noise ratio in an attempt to explore whether a selective impairment in real-time inflectional awareness could be induced in typically-developing participants. Both signal-correlated noise and multi-talker babble noise were used, for replication purposes (of Experiment 2), and because the distinction between real-world and pink noise is important to explore (see section 4.1 for a full rationale). In view of the work of Brungart et al., (2001), the signal-to-noise ratios were 0dB (replication of Experiment 2), -4dB and -8dB. Research by Brungart et al. (2001) suggests that a level noisier than -8dB would result in very poor performance, and a significantly-reduced ability to perceive the underlying speech signal. The aim of this experiment was to investigate subtle changes in inflectional awareness, not to stress the cognitive system so much that perception would be at floor levels. As such, the signal-to-noise ratio did not go below -8dB.

The third person singular -*s* and the regular plural -*s* inflections were the same as Experiment 2; that is, they were matched with regards to phonological saliency. This experiment added in the regular past tense inflection, in view of the comments and suggestions made in 4.4.

The predictions of this experiment were non-directional, as no study has attempted to investigate the real-time inflectional awareness of participants when stimuli were masked by noise. Experiment 2 of this thesis found that a 0dB signal-to-noise ratio impaired overall grammatical sensitivity, and so this finding was expected here on the basis of replication. It was also expected that grammatical sensitivity would be reduced as the signal-to-noise ratio decreased (gets noisier), but it was uncertain whether this deficit in inflectional awareness would be global or selective (as is the case in SLI). Finally, it was expected that the multi-talker babble noise would be more detrimental upon grammatical sensitivity than the signal-correlated noise. This is because a) Experiment 2 found a slight trend for this pattern of results and b) multi-talker babble noise holds more real-language elements than signal-correlated pink noise, and so the level of interference is likely to be higher.

5.2. Method

5.2.1. Participants. A total of 92 children were recruited from Primary schools in York and Cambridge, UK. Children were aged between 7years and 9years, and had a mean age of 101.20 months (SD=6.52 months).

All participants were identified as being 'typically-developing' by their parents and school teacher: There were no reported cases of language, literacy or nonverbal difficulties, and all children reportedly had unimpaired hearing. Refer to chapter 2 for the full details of participant selection and standardised testing.

Children were randomly allocated to one of three signal-to-noise ratio conditions: 0dB, -4dB, -8dB.

5.2.1.1 Initial screening. All children whose parents consented completed various language, nonverbal and attention measures, as detailed in chapter 2. Children were required to achieve age-appropriate scores on all of the measures to complete the experimental part of the study. Four children were excluded as they failed to meet this requirement, and a further four children failed to complete all elements of the experiment. This left a total N for this study of 84.

The details of the test battery scores and group allocations are outlined in table 15. A series of one-way ANOVAs showed that all four groups were comparable with regards to age, gender and test battery scores (all $p>.05$).

Group	N	Age in months (SD)	% female	CELF-IV Expressive Vocabulary (/54)	CELF-IV Word Structures (/32)	WISC Block Design (/68)	Basic auditory RT (ms)
Baseline	20	105.84 (4.25)	50%	23.63	26.89	31.91	389(178)
0dB	21	103.10 (3.23)	52.38%	24.44	30.01	29.54	401(155)
-4dB	22	102.91 (4.54)	45.45%	23.57	26.45	32.34	357(201)
-8dB	21	104.54 (6.01)	57.14%	25.05	27.61	32.47	398(188)
Total mean	*84*	*104.09 (4.51)*	*51%*	*24.17*	*27.74*	*31.57*	*386(181)*

Table 15. Descriptive statistics. Raw data presented here. (exp 3).

5.2.2. Experimental stimuli - Baseline condition. This experiment used a selection of the stimuli from experiment 2 which matched sentences to directly compare the regular plural -*s*and the third person singular -*s*. In view of comments made in section 4.4 regarding a well-rounded simulation of SLI, this experiment also included the regular past tense -*ed* inflection. As far as was practically possible, the sentences assessing awareness of the regular past tense adopted the same format, including the same critical and target words, as the third person singular sentences.

A total of 48 sentences were used in this experiment – 16 assessing the regular plural, 16 assessing the third person singular and 16 assessing the regular past tense inflection. Half of the sentences for each inflection (8) were grammatical, whilst the other half (8) were ungrammatical, such that a bare stem was presented in place of an obligatory inflected form (e.g. *yesterday the boy* ***walk*** *to school with his friends*). Two versions of the stimulus set were created to counterbalance for grammaticality; sentences that were grammatical in set A were ungrammatical in set B and vice-versa. A full stimuli list can be found in Appendix A. There are slightly fewer stimuli items per inflection used in this experiment (but more overall items), as compared to Experiment 2. This is because the regular past tense was added in this experiment, making the overall testing time significantly longer. Children lose attention quickly, and if was felt that too many stimuli items would be detrimental to the results.

Analyses in experiment 2 compared the amplitude and duration of the regular plural and third person singular inflections in an attempt to control for phonological saliency. It was confirmed that the inflections were statistically comparable on both domains. This experiment included the regular past tense and similar phonological analyses were also conducted, as outlined in table 16. A one-way ANOVA revealed a main effect of inflection type upon inflection amplitude (dB) ($F(2,47)=5.17, p=.010$), with post-hoc Bonferroni tests showing the regular past tense inflection to be significantly quieter in amplitude than the regular plural ($p=.018$) and the third person singular ($p=.031$). No significant difference in amplitude was evident between the two *-s* inflections ($p>.05$). This pattern was replicated for analyses of inflection duration: there was a main effect of inflection type upon inflection duration (ms) ($F(2,47)=3.84, p=.029$), with post-hoc Bonferroni tests showing the regular past tense inflection to be significantly shorter in duration than the regular plural ($p=.048$) and the third person singular ($p=.033$). No significant difference was evident with regards to duration between the two *-s* inflections ($p>.05$). With this in mind, it is reasonable to argue that the regular past tense is the least phonologically-salient inflection in this experiment.

Table 16. Mean amplitude and duration of the three morphemes (exp 3)

Word Class	**Amplitude (dB) (SD)**	**Duration (ms) (SD)**
Plural	5.72 (2.51)	0.19 (0.68)
Third Person	5.56 (2.26)	0.21 (0.74)
Past Tense	3.47 (1.80)	0.15 (0.68)

5.2.3. Recording and editing of the stimuli. The target words, associated sentences and comprehension questions were recorded by the experimenter (native English speaker) in a sound-proof room at a sample rate of 44100Hz. Sentences were spoken at a steady rate, with a mean of 188 words per minute (an 'average' conversational rate as defined by Pimsleur et al., 1977 in Tauroza & Allison, 1990).

There were two different types of noise masks used in this study: multi-talker babble and signal-correlated pink noise. These were the same as experiment 2. The noise masks were presented at either 0dB, -4dB or -8dB signal-to-noise ratio, which was manipulated in Audacity. As with previous experiments, the initial presentation of the target word was always presented under no-stress, optimum listening conditions. The sentence which followed this target word was masked according to each child's group allocation (or remained under optimum listening conditions in baseline). After the masked sentence, a comprehension question was presented, again under normal listening conditions.

5.2.4. Intelligibility of stimuli. It was crucial to ensure that the sentences were intelligible in the noise masked conditions. This is so any results could be attributed to the experimental manipulation, rather than intelligibility confounds. Fifty percent of the total stimuli list (total of 24 sentences, half grammatical, half ungrammatical) for each variation (control, 0dB signal-correlated noise, -4dB signal-correlated noise, -8dB signal-correlated noise, 0dB multi-talker babble noise, -4dB multi-talker babble noise, -8dB multi-talker babble noise) were presented to 12 adult participants. The participants were instructed to repeat the sentence verbatim, including any grammatical mistakes. Accuracy rates were very reassuring, as outlined in table 17.

A one-way ANOVA revealed a main effect of condition upon repetition accuracy rates ($F(6,83)=4.13$, $p=.002$). Post-hoc Bonferroni tests showed that there was just a significant difference between the -8dB multi-talker babble noise and baseline ($p=.012$), with the sentences being masked by multi-talker babble at -8dB signal-to-noise ratio being significantly more difficult to repeat than those presented at baseline. There were no other significant differences in repetition accuracy. Given that the other -8dB condition (signal-correlated noise) was not significantly more difficult to repeat than the baseline, and that the accuracy rates were still high in this -8dB multi-talker babble condition (mean of 83.85% words correctly repeated), it was decided to keep the signal-to-noise ratio at this level.

Condition	**Mean % correctly repeated (SD)**
Baseline	94.10 (1.16)
0dB signal-correlated noise	94.09 (1.08)
-4dB signal-correlated noise	92.63 (1.33)
-8dB signal-correlated noise	86.11 (1.56)
0dB multi-talker babble	93.40 (1.31)
-4dB multi-talker babble	92.71 (1.35)
-8dB multi-talker babble	83.85 (1.31)

Table 17. Intelligibility data representing the mean % of sentences correctly repeated verbatim by 12 adult participants, as a function of condition (exp 3)

5.2.5. Design. This experiment compared two noise types (multi-talker babble and signal-correlated pink noise) and three signal-to-noise ratios (0dB, -4dB, -8dB). This experiment adopted a mixed methods design. Noise mask type was a repeated-measures variable and signal-to-noise ratio was an independent groups variable. Grammaticality and inflection were repeated measures variables. As such, there were a total of four groups which children were randomly-allocated to: Baseline (no noise mask, optimum listening conditions), 0dB, -4dB, -8dB. Therefore, any given child who was allocated to an experimental condition (rather than baseline) experienced *all* inflections and *both* grammaticalities and *both* multi-talker babble and signal-correlated noise, all at *one* signal-to-noise ratio.

5.2.6. Procedure. Children were visited in their school during normal teaching hours for two testing sessions, each lasting approximately 35 minutes. The testing sessions were usually one week apart to minimise the likelihood of children remembering the stimuli items.

During the first testing session, children completed half of the standardised measures, a baseline auditory reaction time task and one word monitoring task – either baseline or noise masked at their allocated signal-to-noise ratio. The order of noise mask type (multi talker babble, signal correlated noise) was counterbalanced throughout. In the second testing session, children completed the remaining standardised tests, another baseline auditory reaction time task and the second word monitoring task at the same signal-to-noise ratio as the first task, but under the opposing noise mask. Children allocated to the Baseline condition completed the baseline word monitoring task for a second time in this subsequent testing session.

All of the standardised tests and the basic auditory reaction time task are detailed in chapter 2. A basic auditory reaction time task was always carried out before the word monitoring task in order to give children practice with a fast-response task, and to increase intraparticipant reaction time stability (cf. Montgomery & Leonard, 2006).

An example testing schedule is outlined below in table 18 to clarify the design and procedure.

Child	**Group**		**Session 1** **(Day 1)**			**Session 2** **(Day 7)**	
1	Baseline	½ standardised test battery	Basic auditory RT	Baseline WMT	Remaining ½ test battery	Basic auditory RT	Baseline WMT
2	0dB	½ standardised test battery	Basic auditory RT	0dB multi-talker babble WMT	Remaining ½ test battery	Basic auditory RT	0dB signal-correlated noise WMT
3	-4dB	½ standardised test battery	Basic auditory RT	-4dB multi-talker babble WMT	Remaining ½ test battery	Basic auditory RT	-4dB signal-correlated noise WMT
4	-8dB	½ standardised test battery	Basic auditory RT	-8dB multi-talker babble WMT	Remaining ½ test battery	Basic auditory RT	-8dB signal-correlated noise WMT
5	0dB	½ standardised test battery	Basic auditory RT	0dB signal-correlated noise WMT	Remaining ½ test battery	Basic auditory RT	0dB multi-talker babble WMT
6	-4dB	½ standardised test battery	Basic auditory RT	-4dB signal-correlated noise WMT	Remaining ½ test battery	Basic auditory RT	-4dB multi-talker babble WMT
7	-8dB	½ standardised test battery	Basic auditory RT	-8dB signal-correlated noise WMT	Remaining ½ test battery	Basic auditory RT	-8dB multi-talker babble WMT

Table 18. Example testing schedule for experiment 3.

5.3. Results

5.3.1. Data preparation. Participant reaction times to the target words were calculated in the same manner as experiments one and two (see section 3.3.1 for details). Also analogous to experiments one and two, false data points and non-responses were removed and replaced with the mean for that word class and grammaticality (see section 3.3.1 for details). Finally, reaction time data were log-transformed due to skew, as recommended by Ratcliff (1993). All reaction time analyses for this experiment are based upon log-transformed data, unless otherwise stated.

5.3.2. Word monitoring task

5.3.2.1 Accuracy. There was a relatively low amount of non-responses and false alarms (responses before the target word) in all conditions of the word monitoring task for this experiment, as evidenced by table 19 (note that the table shows total mean raw error scores, which are out of a maximum of 48). Any 'inaccurate' data points on the basis of non-response or false alarm were removed from the data set and replaced by the mean score based on all valid data points for that grammaticality and word class (as per the procedure detailed in section 3.3.1). Overall, 1.04% of responses were removed on the basis of non-response and 1.94% of responses were identified as being false alarms.

Condition	Number of errors (SD)
Baseline	2.645 (1.570)
0dB multi-talker babble	3.164 (2.975)
-4dB multi-talker babble	3.368 (1.745)
-8dB multi-talker babble	4.348 (4.122)
0dB Signal-correlated noise mask	2.850 (1.874)
-4dB Signal-correlated noise mask	3.251 (2.011)
-8dB Signal-correlated noise mask	4.088 (3.997)

Table 19. Mean error rates (false alarms + non-responses) for each condition. Errors were out of a maximum of 48 (exp 3)

A one-way ANOVA was conducted on the error data, with condition as the independent variable and number of errors as the dependent variable. Results showed that there was no main effect of group ($F(6,99)=.74, p>.05$), suggesting accuracy levels were similar across all conditions. It is pertinent to note that there was a slight trend for accuracy to decrease when cognitive stress was increased (i.e. moving into the quieter signal-to-noise ratios), and that the multi-talker babble noise seemed to be associated with slightly more errors than the signal-correlated noise mask.

A bivariate Pearson's correlation was conducted to assess whether there was a speed-accuracy trade-off. That is, were children more likely to make errors when they responded quickly? Data were collapsed across cognitive stress condition because the analysis above showed this not to affect error rates. Results indicate that there was no speed-accuracy trade-off: there was no significant relationship between reaction times in the word monitoring task (mean 579.153ms, SD 294.181ms) and the number of errors made (mean error rate 3.388, SD 2.61) ($r=.201, p>.05$). This suggests that even when children responded quickly, they remained accurate.

5.3.2.2 Grammatical Sensitivity. The overall mean reaction times to the target words are presented in table 20, separated out by noise type and signal-to-noise ratio, but collapsed across word class and grammaticality (both raw and log-transformed data are presented for transparency). A one-way ANOVA showed no main effect of noise mask type upon overall log-transformed reaction times ($F(2,77)=.12, p>.05$). An additional ANOVA revealed no main effect of signal-to-noise ratio upon overall log-transformed reaction times ($F(2,77)=.79, p>.05$). This suggests that reaction times as a whole were similar across the various conditions in this experiment. What is of more interest to this study however, is how the various conditions affected sensitivity to inflectional sensitivity; that is, was the sensitivity to the grammaticality of the various inflections negatively affected by a noisy environment? If so, what type of noise was the most detrimental, and was this impairment selective with regards to inflection type?

The design of this study was complex: There were three noise types (within groups; baseline, signal-correlated noise, multi-talker babble noise), three signal to noise ratios (between groups; 0dB, -4dB, -8dB), two grammaticalities (within groups; grammatical, ungrammatical) and three inflections (within groups; third person singular, regular plural, regular past tense). In view of this complexity, and because of the specific hypotheses posed for this experiment, various smaller ANOVAs will be conducted next to explore the data.

Condition	Mean raw RT (SD)	Mean log RT (SD)
Baseline	**634 (402)**	**2.669 (.216)**
0dB multi-talker babble	595 (395)	2.633 (.216)
-4dB multi-talker babble	626 (377)	2.678 (.120)
-8dB multi-talker babble	632 (226)	2.636 (.162)
Mean multi-talker babble	***617 (333)***	***2.649 (.166)***
0dB signal correlated noise	461 (185)	2.563 (.174)
-4dB signal correlated noise	620 (384)	2.641 (.205)
-8dB signal correlated noise	539 (194)	2.691 (.157)
Mean signal correlated noise	***540 (254)***	***2.632 (.179)***

Table 20. Mean reaction times (raw and log) to the target words in the word monitoring task, as a function of noise type and signal-to-noise ratio (exp 3)

5.3.2.2.1. Assessing the baseline performance. A 3 (inflection: plural, third person, past tense) x 2 (grammaticality: grammatical, ungrammatical) repeated-measures ANOVA was conducted on the log-transformed baseline data. These participants experienced a standard word monitoring task under optimum (no noise) listening conditions. The typical word monitoring task finding was demonstrated: there was a main effect of grammaticality ($F(1,17)=23.76$, $p<.001$), a main effect of inflection ($F(2,34)=3.54$, $p=.040$) and a non-significant interaction between grammaticality and inflection ($F(2,34=.46,p>.05)$). These findings can be seen graphically in figure 10.

It can be seen from figure 10 that target words following a grammatical critical word were responded to faster (mean log reaction time 2.559ms, SD .031; mean raw reaction time 499.70ms, SD 481.71) than those following an ungrammatical critical word (mean log reaction time 2.685ms, SD .0391; mean raw reaction time 769.54ms, SD 664.54). In addition, target words following a plural item were generally responded to faster (mean log reaction time 2.588, SD .082; mean raw reaction time 595.970, SD 622.31) than when they followed a third person singular item (mean log reaction time 2.658ms, SD .091; mean raw reaction time 614.900, SD 477.511). The slowest reaction times were associated with targets following a regular past tense item (mean log reaction time 2.664ms, SD .094; mean raw reaction time 692.405ms, SD 617.987).

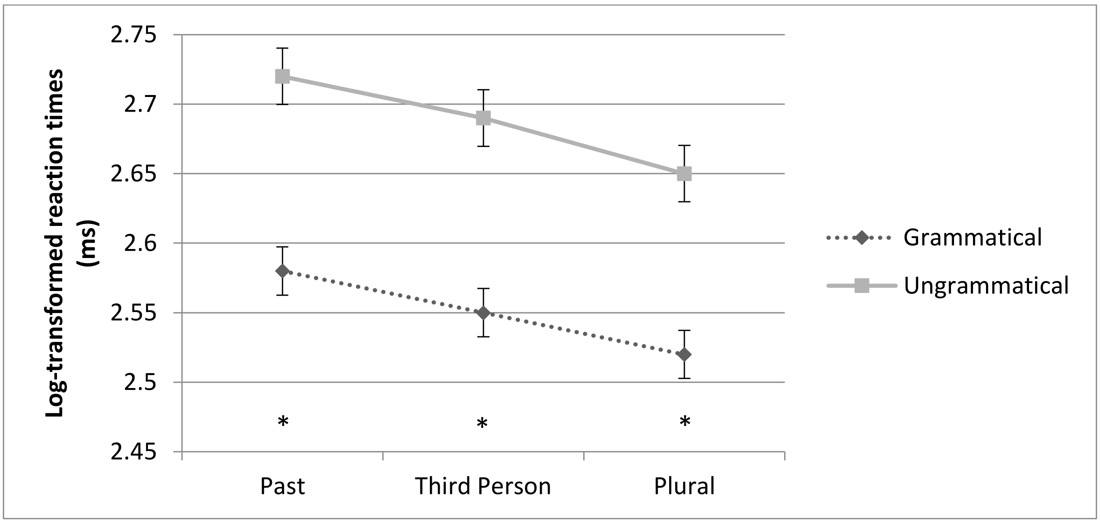


Figure 10. Log-transformed reaction times to the target words in the **baseline condition**, as a function of grammaticality and inflection type. Error bars represent standard error (exp 3). *NB: *denotes t-test significance at the .016 level, adjusted for familywise error rates.*

5.3.2.2.2. Assessing the effect of the different noise types. Table 21 details the mean raw and log transformed reaction time scores to the target words in the word monitoring task, collapsed across signal-to-noise ratios (as it is noise type that is of interest here, not signal-to-noise ratio).

	Multi talker babble		Signal correlated noise	
	Log-transformed	**Raw**	**Log-transformed**	**Raw**
Grammatical Plural	2.525 (.254)	458.759 (390.039	2.526 (.235)	470.488 (416.902)
Ungrammatical Plural	2.612 (.203)	554.055 (571.812)	2.647 (.240)	611.964 (576.928)
Mean Plural	***2.568 (.233)***	***506.407 (480.925)***	***2.586 (.195)***	***541.226 (496.915)***
Grammatical Third Person	2.690 (.239)	525.748 (475.462)	2.542 (.202)	556.196 (450.249)
Ungrammatical Third Person	2.695 (.017)	642.337 (565.221)	2.716 (.202)	624.311 (554.961)
Mean Third Person	***2.692 (.206)***	***584.043 (520.342)***	***2.629 (.198)***	***640.254 (552.605)***
Grammatical Past Tense	2.679 (.188)	609.730 (526.922)	2.526 (.195)	526.983 (370.658)
Ungrammatical Past Tense	2.835 (.243)	648.749 (540.395)	2.670 (.171)	671.278 (483.844)
Mean Past Tense	***2.756 (.229)***	***629.329 (533.659)***	***2.648 (.195)***	***615.462 (445.291)***

Table 21. Mean raw and log transformed reaction time scores (SDs) to the target words in the word monitoring task as a function of noise type, collapsed across signal-to-noise ratios (exp 3)

5.3.2.2.2.1 Multi talker babble. A 3 x (inflection) x 2 (grammaticality) x 3 (signal-to-noise ratio) mixed design ANOVA was conducted on the log transformed multi-talker babble noise mask data. There was a main effect of inflection (F(2,60)=19.68, p<.001), with Pairwise Comparisons indicating that the plurals were responded to faster than the third person (p=.003) and the past tense inflection (p<.001), and that the third person was responded to faster than the past tense inflection (p=.004). Table 21 details the mean scores for reference. There was also a main effect of grammaticality ($F(1,30)=24.71$, $p<.001$), with targets following a grammatical critical word (mean log transformed reaction time 2.632, SD .227) being responded to faster than those following an ungrammatical critical word (mean log transformed reaction time 2.71, SD .205).

There was no main effect of signal-to-noise ratio ($F(2,30)=.68$, $p>.05$), however the grammaticality*signal-to-noise ratio interaction was approaching significance ($F(2,60)=2.96$, $p=.054$), which can be seen graphically in figure 11. The figure suggests that whilst there is an effect of the noise mask upon grammatical sensitivity in the 0dB condition (i.e. there is a large gap between the bars), this effect is reduced in the -4dB and the -8dB conditions (i.e. a smaller gap between the bars). The relative difference in grammatical sensitivity (the magnitude of the gap between the bars) seems to be minimal when one compares the -4dB and the -8dB conditions.

There was a non-significant interaction between inflection*grammaticality ($F(2,60)=2.11$, $p>.05$) and a non-significant three-way interaction between inflection*grammaticality*signal-to-noise ratio ($F(4,60)=1.62$, $p>.05$).

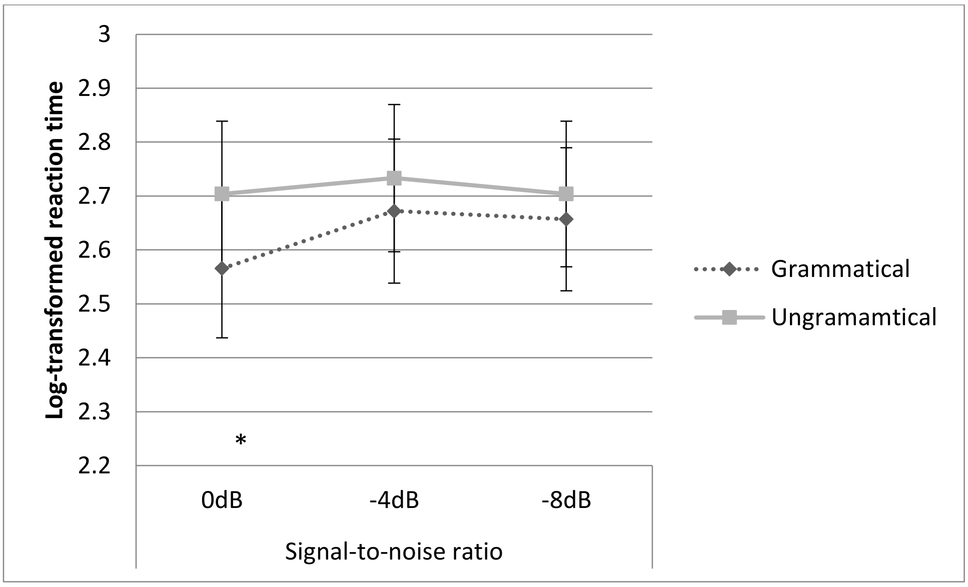


Figure 11. Log-transformed reaction times to target words in the word monitoring task in the **multi talker babble noise mask condition**, as a function of grammaticality and signal-to-noise ratio. Error bars represent standard error (exp 3).

5.3.2.2.2.2 Signal correlated noise. A 3 x (inflection) x 2 (grammaticality) x 3 (signal-to-noise ratio) mixed design ANOVA was conducted on the log transformed signal correlated noise mask data. There was a main effect of inflection ($F(2,60)=4.51$, $p=.045$), with Pairwise Comparisons indicating that the plurals were responded to faster than the third person ($p=.035$) and the past tense inflection ($p=.020$), and that the third person was responded to faster than the past tense inflection ($p=.039$). Table 21 details the mean scores for reference. There was also a main effect of grammaticality ($F(1,30)=74.53$, $p<.001$), with targets following a grammatical critical word (mean log transformed reaction time 2.531ms, SD 0.211ms) being responded to faster than those following an ungrammatical critical word (mean log transformed reaction time2.678ms, SD 0.204ms). There was no main effect of signal-to-noise ratio ($F(2,30)=.68$, $p>.05$), and non-significant interactions between grammaticality*signal-to-noise ratio ($F(2,60)=2.12$,p=.>.05), inflection*grammaticality ($F(2,60)=2.19$,$p>.05$) and inflection*grammaticality*signal-to-noise ratio ($F(4,60)=1.91$,$p>.05$).

For the purpose of comparison between the multi-talker babble noise, the (non-significant) interaction between grammaticality*signal-to-noise ratio for the signal correlated noise mask is shown in figure 12. The lack of interaction is quite plain in figure 12: The magnitude of the gap between the bars which indicates grammatical sensitivity seems to be reasonably consistent across all three signal-to-noise ratios.

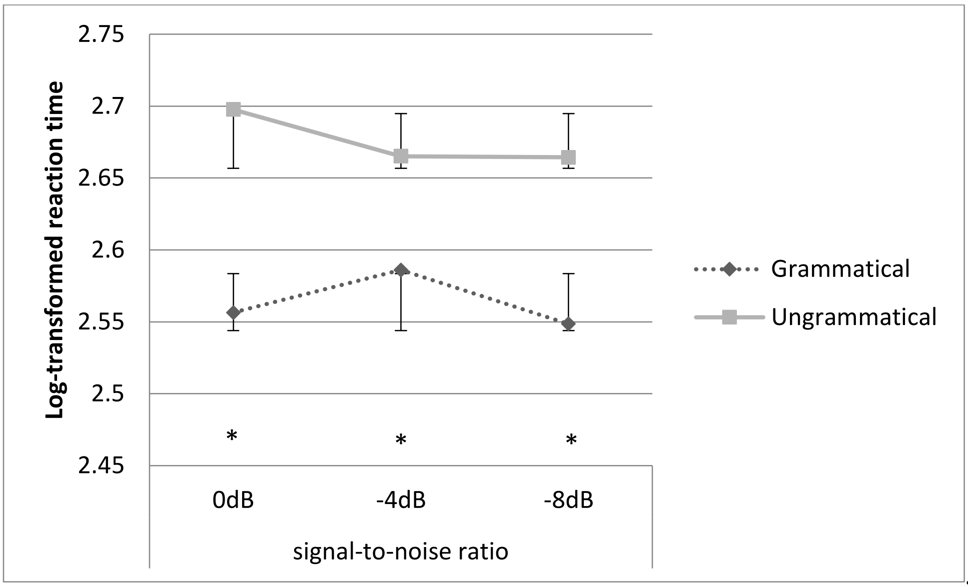


Figure 12. Log-transformed reaction times to target words in the word monitoring task in the **signal correlated noise mask condition,** as a function of grammaticality and signal-to-noise ratio. Error bars represent standard error (exp 3)

5.3.2.2.3. Assessing the effect of the signal-to-noise ratios. Table 22 details the mean raw and log transformed reaction times to the target words in the word monitoring task, separated by signal-to-noise ratio, inflection and grammaticality, and collapsed across noise mask type (as it is signal-to-noise ratio that is the main factor of interest here).

	0dB		-4dB		-8dB	
	Log-transformed	**Raw**	**Log-transformed**	**Raw**	**Log-transformed**	**Raw**
Grammatical Plural	2.521	426.813	2.555	475.261	2.563	438.272
	(.178)	(292.385)	(.247)	(308.537)	(.201)	(262.654)
Ungrammatical Plural	2.612	588.262	2.691	588.389	2.682	596.559
	(.201)	(427.949)	(.223)	(379.601)	(.199)	(384.961)
Mean Plural	***2.566***	***507.538***	***2.626***	***531.825***	***2.609***	***517.416***
	(.194)	***(360.167)***	***(.235)***	***(353.069)***	***(.200)***	***(323.808)***
Grammatical Third Person	2.627	481.529	2.636	525.469	2.668	547.791
	(.199)	(296.694)	(.187)	(326.211)	(.195)	(312.076)
Ungrammatical Third Person	2.721	646.577	2.757	677.499	2.879	636.051
	(.177)	(582.317)	(.200)	(446.478)	(.230)	(326.578)
Mean Third Person	***2.674***	***564.053***	***2.697***	***601.484***	***2.774***	***591.921***
	(.188)	***(439.505)***	***(.194)***	***(386.345)***	***(.213)***	***(319.327)***
Grammatical Past Tense	2.618	519.662	2.698	578.451	2.711	604.214
	(.159)	(349.968)	(.213)	(345.869)	(.227)	(224.496)
Ungrammatical Past Tense	2.697	688.544	2.759	692.579	2.744	706.461
	(.241)	(378.439)	(.176)	(434.387)	(.187)	(347.348)
Mean Past Tense	***2.658***	***604.103***	***2.729***	***585.515***	***2.728***	***655.376***
	(.200)	***364.204***	***(.195)***	***(390.128)***	***(.207)***	***(285.922)***

Table 22. mean raw and log transformed reaction times to the target words in the word monitoring task, separated by signal-to-noise ratio, inflection and grammaticality, and collapsed across noise mask type (exp 3)

5.3.2.2.3.1 0dB signal-to-noise ratio. A 2 (noise mask type: multi talker babble; signal-correlated noise) x 3 (inflection: past tense; third person singular; plural) x 2 (grammaticality: grammatical; ungrammatical) repeated measures ANOVA was conducted on the data from the 0dB signal-to-noise ratio group.

There was a main effect of inflection ($F(2,38)=22.87$, $p<.001$), with post-hoc Bonferroni tests showing that targets following past tense constructions were responded to slower than those following third person singular constructions ($p<.001$) and regular plurals ($p<.001$). In addition, third person singular constructions were associated with slower reaction times than regular plural constructions ($p<.001$). There was also a main effect of grammaticality ($F(1,19)=42.74$, $p<.001$) such that targets following grammatical constructions were responded to faster (mean raw RT 476ms, SD 313ms, mean log RT 2.589ms, SD .179ms) than targets following ungrammatical constructions (mean raw RT 641ms, SD 462ms, mean log RT 2.677ms, SD .206ms). The main effects of inflection and grammaticality can be seen in figure 13. However, there was a significant grammaticality*noise mask type interaction ($F(1,19)=8.91$, $p=.008$). By looking at the figures in tables 21 and 22, it appears that whilst there was sensitivity to grammaticality when sentences were masked by signal-correlated noise, this sensitivity was less pronounced when sentences were masked by multi-talker babble noise.

There were nonsignificant interactions between inflection*noise mask type ($F(2,38)=1.28$, $p>.05$), inflection*grammaticality ($F(2,38)=.06$, $p>.05$) and inflection*grammaticality*noise mask type ($F(2,38)=2.72$, $p>.05$). In addition, the main effect of noise mask type was nonsignificant ($F(1,19)=1.41$, $p>.05$).

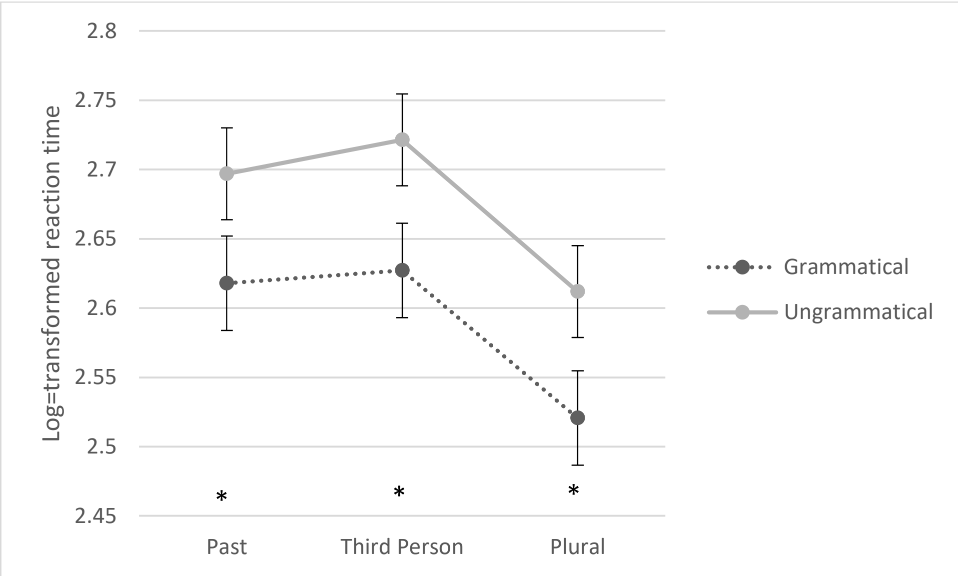


Figure 13. Log-transformed reaction times to targets in the **0dB signal-to-noise ratio condition**, collapsed across the two noise types. Error bars represent standard error (exp 3). *NB: * denotes t-test significance at the .016 level, adjusted for familywise error rates.*

5.3.2.2.3.2 -4dB signal-to-noise ratio. A 2 (noise mask type: multi talker babble; signal-correlated noise) x 3 (inflection: past tense; third person singular; plural) x 2 (grammaticality: grammatical; ungrammatical) repeated measures ANOVA was conducted on the data from the -4dB signal-to-noise ratio group.

There was a main effect of inflection (*F*(2,36)=4.82, p=.014), with post-hoc Bonferroni tests only showing a significant difference in reaction times between past tense and regular plural sentences (p=.021). There was also a main effect of grammaticality (*F*(1,18=12.73, p=.002) such that targets following grammatical constructions were responded to faster (mean raw RT 526ms, SD 317ms, mean log RT 2.629ms, SD .215ms) than targets following ungrammatical constructions (mean raw RT 652ms, SD 420ms, mean log RT 2.736ms, SD .199ms). In contrast to the 0dB signal-to-noise ratio condition, the grammaticality*noise mask type interaction was nonsignificant (*F*(1,18)=2.49, p>.05).

As with the 0dB condition, there were nonsignificant interactions between inflection*noise mask type (*F*(2,36)=.58, p>.05), inflection*grammaticality

(*F*(2,36)=2.69, p>.05) and inflection*grammaticality*noise mask type (*F*(2,36)=.03, p>.05). In addition, the main effect of noise mask type was nonsignificant (F*(*1,18)=.51, p>..05).

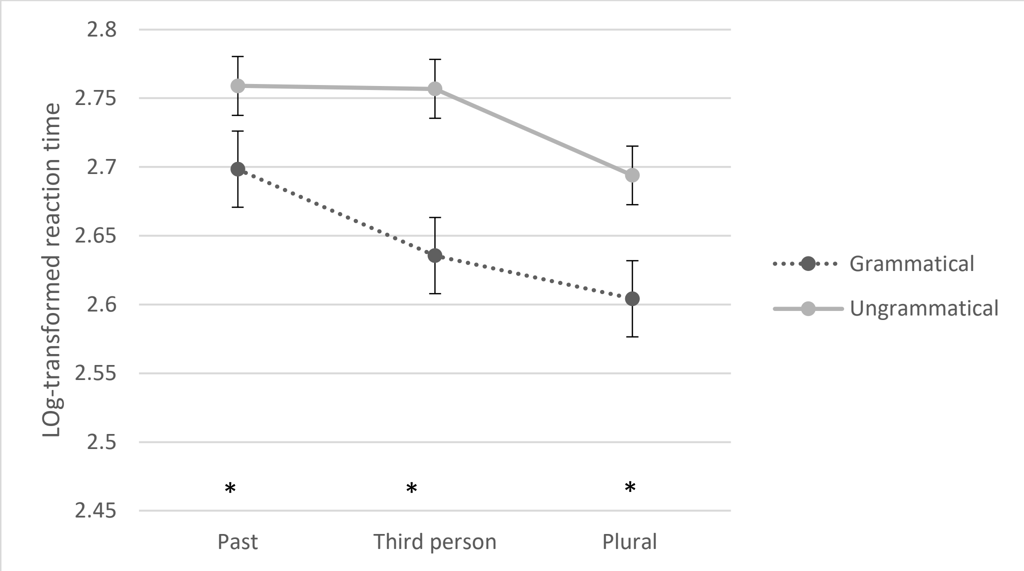


Figure 14. Log-transformed reaction times to targets **-4dB signal-to-noise ratio condition**, collapsed across the two noise types. Error bars represent standard error (exp 3). *NB: * denotes t-test significance at the .016 level, adjusted for familywise error rates.*

5.3.2.2.3.3 -8dB signal-to-noise ratio. A 2 (noise mask type: multi talker babble; signal-correlated noise) x 3 (inflection: past tense; third person singular; plural) x 2 (grammaticality: grammatical; ungrammatical) repeated measures ANOVA was conducted on the data from the -8dB signal-to-noise ratio group.

There was a main effect of inflection (*F*(2,36)=6.83, p=.003), with post-hoc Bonferroni tests only showing a significant difference in reaction times between past tense and regular plural sentences (p=.017). There was also a main effect of grammaticality (*F*(1,18)=54.36, p<.001) such that targets following grammatical constructions were responded to faster (mean raw RT 526ms, SD 326ms, mean log RT 2.647ms, SD .208ms) than targets following ungrammatical constructions (mean raw RT 646ms, SD 352ms, mean log RT 2.768ms, SD .205ms). In contrast to the

0dB signal-to-noise ratio condition but similar to the -4dB group, the grammaticality*noise mask type interaction was nonsignificant (*F*(1,18)=1.53, p>.05).

As with the 0dB and -4dB conditions, there were nonsignificant interactions between inflection*noise mask type (*F*(2,36)=2.45, p>.05), inflection*grammaticality (*F*(2,36)=3.15, p>.05) and inflection*grammaticality*noise mask type (*F*(2,36)=3.12, p>.05). In addition, the main effect of noise mask type was nonsignificant (*F*(1,18)=1.09, p>.05).

It is pertinent to note that although the interaction between inflection and grammaticality was nonsignificant in this condition, it appears that sensitivity to grammaticality in the regular past tense is becoming impaired (see figure 15).

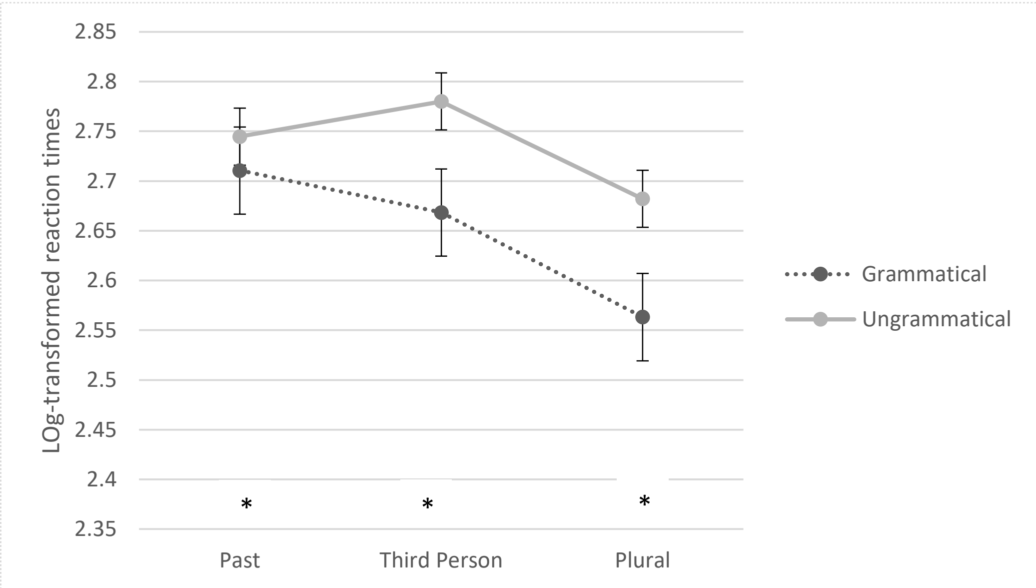


Figure 15. Log-transformed reaction times to targets in the **-8dB signal-to-noise ratio condition**, collapsed across the two noise types. Error bars represent standard error(exp 3). *NB: * denotes t-test significance at the .016 level, adjusted for familywise error rates.*

5.4. Discussion

This third experiment of the thesis aimed to build upon the results from Experiment 2 by further examining the noise mask cognitive stressors. Experiment 2 used two types of noise mask, multi-talker babble and signal-correlated noise, at *one* signal-to-noise ratio (0dB). Section 4.4 highlighted that the noise mask may not have been noisy enough, given the nonsignificant effect of the stressor upon grammatical sensitivity. In view of this, the current experiment sought to systematically manipulate the signal-to-noise ratio of the two noise masks, in an attempt to 'calibrate' the level akin to what was done with speed in Experiment 1. Two noise masks were used (multi-talker babble and signal-correlated noise) at three increasingly-noisy signal-to-noise ratios: 0dB, -4dB, -8dB. Children were asked to complete two word monitoring tasks, one for each noise type, at one of the three signal-to-noise ratios. There was also a control condition in which children completed the word monitoring task under optimum listening conditions.

The results of this study are complex and multi-faceted. Accuracy was the first element of the results to be analysed, and so this will be the first to feature in this discussion section. Next, grammatical sensitivity will be explored, with reference to the varying noise masks and signal-to-noise ratios. Theoretical implications and further directions will be subsequently explored, before drawing conclusions from the data in this third experiment.

5.4.1. Accuracy. The term accuracy in the word monitoring task refers to the number of errors made when responding to the target word. Errors can either be false alarms or non-responses, which are presses before the target occurs and no response at all, respectively. Accuracy rates were very high in this experiment, even in the noisiest (-8dB) conditions. Although there did appear to be a very slight trend for accuracy rates to decrease as the noise mask got louder, this effect was not significant. These high accuracy rates are very reassuring: they suggest that the sentences are entirely intelligible to the children (because if children couldn't hear the targets within the sentences, their accuracy rates would be low), and that any impairment in grammatical awareness is not likely to be due to poor accuracy. Further analyses on the accuracy data revealed no speed-accuracy trade-off, which provides further reassurance that the children were really focussing on the task at hand, and not simply trying to respond as quickly as possible, without regard for precision.

5.4.2. Grammatical sensitivity. There was no main effect of signal-to-noise ratio or noise mask type upon overall reaction times to the target words in the word monitoring task, which suggests that reaction times as a whole were similar across the various conditions in this experiment. It is important to remember that children with SLI respond slower than typically-developing children in the word monitoring task (Montgomery & Leonard, 2006). The lack of effect of noise stressor upon reaction times demonstrates that although the inflectional sensitivity of cognitively-stressed typically-developing children may 'look' like the grammar of children with SLI, their response times do not. That is, when placed under cognitive stress, a typically-developing child's grammatical sensitivity will become impaired, but their overall reaction times do not. This is likely to be because this paradigm stresses an auditory domain, not a speed of processing one. This is supported by the altered reaction times to speeded sentences in experiments one and two: when we stress a speed domain, speed of processing is affected.

What is of more interest to this study however, is how the various conditions affected sensitivity to grammaticality; that is, was sensitivity to grammaticality negatively affected by a noisy environment? If so, what type of noise was the most detrimental, and was this impairment selective with regards to inflection type?

5.4.2.1 Assessing the baseline performance and comparisons to the SLI hierarchy. Participants in the baseline condition (no noise, optimum listening conditions) demonstrated the standard word monitoring task effect. That is, children responded to targets following a grammatical item faster than targets following an ungrammatical item. This differential performance between the two grammaticalities implies that, on some level, children are sensitive to the grammaticality within the sentences. This finding also tells us that grammatical responsiveness is somewhat automatic: the difference in grammatical-ungrammatical reaction times is often a matter of milliseconds, which is far beyond the sensitivity of the conscious mind. What is does not tell us however is what ‘level’ this lies at with regards to offline awareness: were children consciously mindful that there were grammatical mistakes in the sentences once heard, and if so, were they aware of where those grammatical mistakes lay? To answer these questions, a grammaticality judgement task needs to be performed. However, grammaticality judgement tasks come with their own shortcomings, as discussed in chapter 2.

In addition to the grammatical-ungrammatical reaction time difference, there was a clear hierarchy of reaction time speed with regards to the specific inflections, with targets following noun items being responded to fastest, followed by those after a third person singular inflection, and finally those that occurred after a regular past tense inflection. This hierarchy of reaction time speed directly mirrors the hierarchy of inflectional difficulty seen in children with SLI, and is somewhat reflective of the typical order of morphological acquisition, as detailed in section 1.1.1. It is argued (e.g. Chiat, 2000) that this pattern of differential inflectional difficulty is present in SLI because of the ‘difficulty’ level of the inflections, with regards to grammatical complexity and phonological saliency (among other properties). For instance, the plural *-s* inflection is relatively ‘easy’, in that it is phonologically salient and it is centred around a word class that is usually concrete in nature (see section 1.3.3.2 for an in-depth discussion). Verbs are inherently more difficult because they are usually less concrete than nouns, and because they often refer to relational constructs (see section 1.3.3.2 for a review). The two verb inflections are also less phonologically salient than the regular plural *-s* inflection. Within the verb word class, the third person singular *-s* inflection is more phonologically salient than the regular past tense *-ed* inflection, which possibly explains why it ‘easier’ to process and is less likely to be affected by cognitive stress.

Leading on from concrete-ness, it is felt that it is easier to demonstrate to a child an action that is happening in real time than something that happened in the past. In the simplest situation, one could show a child a picture of a girl stroking a dog alongside the sentence “every day the girl strokes the dog” to demonstrate the action of stroking in the third person singular tense. However, to demonstrate the action of stroking in the past tense, one must show a child a picture of the girl stroking the dog, and an additional picture of just the dog accompanied with the sentence "here is the dog that the girl stroked", or something to the same effect. In a real-world situation, a child can actually *see* an example in real-time of a girl stroking a dog. However, to experience the past tense in a real-world situation, that child would not only have to call upon their grammatical knowledge, but also their memory to remember what action happened in the past.

It is interesting that the typically-developing children of this study demonstrated an SLI-like pattern of inflectional difficulty in their word monitoring task reaction times, even in optimum listening conditions. That is, reaction times to targets following a plural item were the fastest, followed by the third person singular inflection, and finally the regular past tense. These are children whose grammatical knowledge does not ordinarily follow this hierarchy, as all three inflections are mastered by this age (cf. Brown, 1973), and children showed near-perfect levels of performance on the CELF-IV Word Structures subtest, which is a measure of inflectional ability. This implies that, despite the children appearing to have acquired complete mastery of these inflections, there lies some hierarchy of difficulty within their grammatical lexicon that becomes evident when we begin to look at very subtle analysis, such as reaction times. It is also pertinent to note that, as the pattern is the same in both populations (typically-developing and SLI), it appears that children with SLI are simply delayed, rather than deviant in their grammatical capacity.

5.4.2.2 Assessing the effect of the noise masks. Both noise masks resulted in the 'standard' word monitoring task findings: targets following a grammatical critical word were responded to faster than those following an ungrammatical critical word; targets following a regular past tense item were associated with the slowest reactions times, in comparison to the third person singular and the regular past tense inflections. The third person singular -*s* inflection was, in turn, associated with slower reaction times than the regular plural -*s* inflection.

However, it was only the multi-talker babble noise mask that resulted in a significant grammaticality*signal-to-noise ratio interaction. The data shows that whilst children demonstrated a reasonable level of grammatical sensitivity for sentences masked by multi talker babble at a 0dB signal-to-noise ratio, their sensitivity was reduced for sentences masked at -4dB and -8dB signal-to-noise ratios. That is, as the noise mask got noisier, the children were less able to detect ungrammaticality in all sentences, regardless of the critical words' word class. There were no significant interactions with inflection type, suggesting that all three inflections were impaired in a similar way in all signal-to-noise ratios. In view of this, there does not appear to be an SLI-like pattern of inflectional difficulty when sentences are masked by multi talker babble noise; rather all inflections were equally impaired (or unimpaired in the 0dB condition). However, it must be noted that in the multi-talker babble-8dB signal-to-noise ratio condition, sensitivity to the regular past tense started to reduce (i.e. the gap between the lines reduced). Whilst one must exercise caution in interpreting 'trends' rather than significant findings, it is interesting nonetheless to see that the most 'difficult' inflection does start to fall apart when a very difficult noise mask is introduced. It would be interesting to see the effects on inflectional sensitivity when the signal-to-noise ratio is *even harder* than -8dB, although the work of Brungart et al., 2001 (combined with anecdotal evidence from testing the children) suggests that floor effects would nullify the results.

In contrast to the multi-talker babble condition, the signal-correlated noise mask had a slightly different effect on grammatical sensitivity. There was no significant grammaticality*signal-to-noise ratio interaction in this condition, and by looking the data it seems quite plain that the signal correlated noise mask was not as detrimental to grammatical sensitivity as the multi-talker babble noise mask was. With the multi-talker babble noise, children's grammatical sensitivity was reduced across the board when the noise mask was at -4dB and -8dB relative to the underlying signal. However, with the signal correlated noise mask, children's grammatical sensitivity was still evident even in the noisiest (-8dB) condition.

This difference in performance between the two noise masks and various signal-to-noise ratios was not found in Experiment 2, in which both masks, which were placed at 0dB signal-to-noise ratio, resulted in a significant main effect of grammaticality (and therefore no impairment to inflectional awareness). The current experiment replicated this particular finding, which is evidenced visually by both masks being associated with bars far apart for the 0dB condition. It was suggested in Experiment 2 that the noise was not noisy enough at 0dB to impair grammatical sensitivity, and this indeed seems to be the case, at least for the multi-talker babble noise mask. Pushing the signal-to-noise ratio down to -4dB seemed to be enough to degrade grammatical sensitivity, but not in the selective manner we see in SLI, or when we speed sentences by 30% (see experiments one and two). Interestingly, signal-correlated noise still did not affect grammatical processing, even in the noisiest condition.

Although both masks are energetic in nature, the multi-talker babble noise mask carried slightly more of an informational element as it was composed of real-world language, although the use of many talkers (6) minimizes this information element compared to a small number of talkers (Mattys, Brooks & Cooke, 2009). This is in comparison to the signal-correlated noise mask that was on the same speech spectrum as everyday speech, but did not contain lexical items. The multi-talker babble noise mask seemed to interfere with the grammatical processing in the word monitoring task more than the signal-correlated noise did, as evidenced by an increase of errors and a more dramatic impairment in overall grammatical sensitivity (as measured by reaction times) throughout the signal-to-noise ratios. Presumably this is because the higher informational element makes it more difficult, and more likely to interfere with processing of the underlying critical speech signal.

Conversely, the signal-correlated noise did not seem to interfere as much with grammatical processing, although it did have a slightly negative impact on overall performance in the word monitoring task. That is, there were small (but nonsignificant) increases in the number of errors made in the word monitoring task, and a small decrease in the grammatical-ungrammatical reaction time discrepancy.

The reason behind using a signal-correlated mask, rather than a static one, was due to the fluctuating phonological intensity of the underlying signal: Every element of a spoken utterance varies in phonological saliency, with the morphological items generally being the least salient aspects. It was argued in section 4.4 that a static noise mask would therefore ‘unfairly’ mask the inflections, as these are the weakest parts of the sentence, phonologically-speaking. As such, an amplitude-fluctuating noise mask was created which mirrored the phonological saliency of the underlying speech signal. That is, it was quieter when masking the quieter parts of the sentence, and louder when masking the louder parts of the sentence. The multi-talker babble noise did not have this element to it – it had constant amplitude. Whilst it cannot be denied that the literature consistently demonstrates that masks with more informational elements are more detrimental to language processing than those with less informational content (see Mattys, Brooks & Cooke, 2009; Mattys et al., 2012), it may be the case that the static nature of the multi-talker babble mask in this experiment made it even more difficult. Section 4.1 explains that individuals make use of glimpses when listening to speech in noise, but this is only possible when the signal's amplitude is fluctuating. A static-amplitude noise mask, such as the multi-talker babble used in this experiment, does not allow listeners to utilise glimpses. Accordingly, it cannot be concluded that the multi-talker babble noise was more detrimental to grammatical sensitivity than the signal-correlated noise because it had more informational elements. It may have been more detrimental because it had less glimpses, given its static amplitude. An experiment that includes four levels of noise mask would help disentangle this issue: static multi-talker babble, static pink noise, signal-correlated multi-talker babble, signal-correlated pink noise.

5.4.3. Future directions, summary and conclusions. This third experiment of the thesis showed that even when carefully calibrated, a noise mask cannot simulate the SLI-like hierarchy of inflectional difficulty in typically-developing children, at least within the confines of the word monitoring task. A noise mask can impair overall grammatical sensitivity, but that is likely to be simply because the noise mask makes the task harder, on the most basic level. This suggests that there is indeed something special about Speed of Processing, as this is the only stressor in this thesis that has been able to successfully (and statistically) simulate an SLI-like inflectional hierarchy.

Interestingly, the typically-developing children in this study showed the same hierarchy of inflectional difficulty in their baseline responses as children with SLI do in their expressive and receptive language. That is, the regular past tense was the most problematic (in this experiment, targets following these constructions were associated with the slowest reaction times), followed by the third person singular, and then the regular plural. This gives rise to the idea that there is a somewhat fundamental hierarchy of complexity within English morphology, and that, despite full competency on the surface, typically-developing children are instinctively sensitive to this hierarchy. This finding also lends support to the argument that children with SLI are not deviant in their morphological representations, rather they may simply be delayed.

Moving on to assessing the two specific noise masks, this study found that a multi-talker babble noise mask was more detrimental to grammatical sensitivity than a signal-correlated pink noise mask. However, the reasons for this differential level of difficulty remains unclear from this particular study. The design of the two noise masks mean that it is not possible to establish whether the multi-talker babble was more difficult because of its increased informational element, or because of its lack of amplitude fluctuation (which would facilitate the utilisation of glimpses). Further work with more tightly-designed noise masks (including multi-talker babble utilising a small number of speakers to increase informational load) is needed to fully explore these ideas.

The acoustic analyses of the stimuli revealed that the regular past tense inflection was indeed less phonologically-salient than both the third-person singular and the regular plural inflections, which were in turn matched with regards to phonological saliency. This finding, combined with the other findings of the experiment, lends further support for the Surface Hypothesis. In the baseline condition, the participants demonstrated the classical SLI hierarchy of difficulty, with the past tense being associated with the worse performance (least salient) and the plural being associated with the best performance (most salient). The lack of specific effect of either noise mask strengthens the Surface Hypothesis's argument that the inflectional difficulties in SLI are the result of a complex interplay between speed of processing and phonological saliency; throughout this thesis, the classical hierarchy of difficulty has only been evidenced when stimuli were speeded.

Therefore, it is not the case that simply ‘any stressor will do’; it appears to be speed specifically.

Collectively, the data gathered throughout this thesis so far indicates that it is indeed speed that is the ‘key’ stressor in order to simulate the inflectional difficulties seen in SLI. The three experiments in this thesis so far have all sought to simulate SLI by stressing cognitive load. To provide a more comprehensive account of the mechanisms mediating inflectional impairments in SLI, one could attempt to ‘ease’ the stress in children with SLI, effectively ‘reversing’ the simulation paradigm.

Chapter 6. Experiment 4: Reversing the paradigm in children with SLI

6.1. Introduction

The experiments within this thesis so far have shown some promising results. It appears that the specific profile of inflectional difficulty seen in SLI can indeed be simulated in TD children by speeding sentences up by 30% in a word monitoring task. Lengthening sentences had no effect, and introducing a noise mask in order to degrade the quality of the incoming speech signal did not have a *specific* effect on inflectional processing, although it did have a detrimental effect on overall performance in the word monitoring task.

This presents a strong case regarding the underlying cognitive deficit in SLI: Children with SLI may demonstrate a specific profile of inflectional difficulty because they may have impaired speed of processing. That is, they might struggle to process incoming speech in a time-effective manner. In order to further test this hypothesis, one could investigate whether the impairments in SLI can be alleviated by *slowing* stimuli rates down. It has already been shown that typically-developing children demonstrate SLI-like grammatical deficits when sentences are sped up by 30%. Examining whether children with SLI can show typically-developing-like grammatical performance when sentences are slowed down by 30% would help investigate this hypothesis.

There is a small body of literature that has investigated the language skills of children with SLI when sentence presentation rate is slowed. For instance, Montgomery (2004) noted that when sentences were presented at a normal rate, children with SLI demonstrated worse sentence comprehension skills than both age- and language-matched controls. When sentences were slowed down by 25%, the children with SLI performed as well as the language-matched group on sentence comprehension, however their performance remained below that of the age-matched group. In addition, Fazio (1998) found that children with SLI had serial recall abilities comparable to age-matched controls when items were presented at a slower rate, but worse than controls when items were presented at a normal/baseline speed. Finally, Montgomery (2005) noted that children with SLI showed significantly better word monitoring task performance when the stimuli articulation rate was slowed by 25%.

The three studies discussed above (Fazio, 1998, Montgomery, 2004; 2005) were able to show that language performance can be improved in children with SLI by slowing down sentence presentation rate, suggesting that speed of processing is a factor to be considered in the aetiology of SLI. However, no study was found in the peer-reviewed literature that attempts to alleviate the *inflectional* difficulties in SLI by slowing stimulus presentation rate. Given that difficulties with inflectional morphology are one of the key features of SLI, this should be researched. The current study therefore fills an important gap in the literature.

Throughout this thesis, the experiments have adopted a word monitoring task as a way to measure online or real-time inflectional processing. The experiments in this thesis have looked to simulate the typical SLI inflectional hierarchy of difficulty in the reaction times of typically-developing children. That is, reaction times to targets following an ungrammatical past tense construction should be the same as reaction times to targets following a grammatical past tense construction, when the task is performed under cognitive stress (suggesting impaired sensitivity as both grammaticalities would be treated equally). In the same vein, reaction times to targets following an ungrammatical noun construction should remain significantly slower than reaction times to targets following a grammatical construction despite cognitive stress.

Although this pattern simulates what is consistently seen in the SLI population (see Leonard, 2014 for a review, and1.3.3), it is largely seen in natural language samples (e.g. Rice & Oetting, 1993),) and grammaticality judgment paradigms (e.g. Hayiou-Thomas et al., 2004). To my knowledge, there is no study that has confirmed whether children with SLI demonstrate this hierarchy of difficulty in the word monitoring task, when it is performed at baseline (optimum) listening conditions. There has been research that has asked children with SLI to complete a word monitoring task at baseline (e.g. Montgomery & Leonard, 2006), but this research has not looked to confirm whether their inflectional hierarchy is present in the data. Whilst it would seem logical to predict that children with SLI would show their classic pattern of deficits, it cannot be assumed that this is the case. This needs to be confirmed, and so this was the first aim of this experiment: To establish whether children with SLI show deficits in the word monitoring task that reflect the deficits we see in their naturalistic and off-line language.

If deficits were shown in the SLI sample, a secondary aim of this experiment was to explore the possibility of alleviating these deficits by slowing the speech signal down.

With these aims in mind, this study recruited a sample of children with SLI, and asked them to perform a word monitoring task under normal-rate (baseline) and 30% slower presentation rates. The regular past tense, third person singular and the regular plural inflections featured in this study.

With regards to specific predictions, it was expected that the overall word monitoring task performance of the children with SLI would improve in the slow-rate condition, as compared to the normal-rate condition (i.e. their reaction times would improve). This is in accordance with the findings of Montgomery (2004, 2005 and Fazio (1998). Due to the complete dearth of literature in the area, it was not known what direction the results will take with regards to performance on specific inflections, or whether the children with SLI would even demonstrate their classical hierarchy of impairment in the baseline word monitoring task.

6.2. Method

6.2.1. Participants. To be included in this study, children needed an SLI profile of language impairment. That is, scores on nonverbal standardised measures needed to be within the normal range, whilst scores on the verbal measures needed to fall below the normal range. As chapter 2 details, numerous tests comprised the test battery for this experiment. Children completed five language measures, which are outlined in table 23. In order to be included in this study, children needed to have scored below the normal range in at least two of the five measures, as well as scoring within the normal range on the WISC-IV Block Design subtest (a popular measure of nonverbal ability). The vast majority of the children who completed all parts of this experiment scored below the normal range in four of the five measures.

Children were recruited through two language units in Yorkshire, which were managed by Local Education Authorities. These language units provided specialist support in language and communication to children in the form of half-day group sessions. All children who attended the language units still completed the vast majority of their education in a mainstream primary school. All children attended the language unit for two half-day (2.5hour) sessions a week. Whilst at the language unit, children would work in small groups (between 2-4 children per group) on a wide variety of language skills, including vocabulary, grammar and comprehension. Activities were really varied, but some examples include shared storybook reading, naming of pictures on flash cards and phonological awareness tasks.

A total of 56 children were screened using the standardised language and nonverbal measures outlined in table 23. Of these 56 children, seven were excluded because they had communication, not language, difficulties. Twelve children were excluded because English was their second language, and their language difficulties were simply due to this, rather than a specific deficit. Three children were excluded for hearing impairments, and a further six children were excluded because they failed to understand the task demands. Finally, 11 children were excluded because their language skills were in the typical range on all of the standardised measures (in ten of these cases the children were being prepared for discharge from the language unit). This resulted in a total N of 17 children for this experiment.

Of these 17 children, 12 were male. The mean age was 103.31 months (SD 8.93 months; range 87-119 months). The standardised test details of this sample are outlined in table 21. Children performed substantially worse than expected given their chronological age in all but the nonverbal (block design) subtests. The block design scores all fell within the normal range, given their chronological age. This reflects the classic discrepancy definition of SLI.

Standardised test	Mean raw score (SD)
CELF-IV Expressive Vocabulary (/54)	20.78 (4.01)
BPVS-3 (/168)	69.24 (5.41)
CELF-IV Word Structures (/32)	16.14 (4.39)
CELF-IV Recalling Sentences (/96)	14.33 (3.99)
CNRep (/40)	8.01 (2.47)
WISC-IV Block Design (/68)	29.14 (4.10)

Table 23. Mean raw scores on the standardised language measures administered (exp 4)

6.2.2. Materials. In addition to the various standardised tests outlined in table 21, the participants of this study completed a basic auditory reaction time task and a flanker task. These tasks were the same as what were administered in experiment 3.

There were two word monitoring tasks used in this experiment: normal baseline speed and 30% slower than baseline. The stimuli were the same as experiment 3: there were three inflections (regular past tense, third person singular, regular plural) and 16 sentences per inflection (8 grammatical and 8 ungrammatical), resulting in 48 sentences in total. The critical words were homophones, such that they were either a noun or verb depending on the sentence context. This helped to minimise phonological and articulatory confounds in the stimuli (see section 5.2 for a detailed overview of the stimuli controls). There were two sentence sets to balance for grammaticality: Sentences that were grammatical in set A were ungrammatical in set B and vice versa. Children completed both set A and set B over the two testing sessions in a counterbalanced order (see table 24 for clarification and Appendix A for a full list of stimuli).

For the 30% slower stimuli, sentence articulation rate was slowed down in PRAAT in the same manner that sentences were sped up for experiments 1 and 2 of this thesis. The algorithm in PRAAT was chosen as it changes the temporal profile without affecting the spectral pattern (so sentences were slowed but still sounded natural). As with the other experiments in this thesis, the target word at the start of each trial was always presented under optimum listening conditions.

After each sentence, a comprehension question was asked (see Appendix A), which was also presented under optimum listening conditions.

6.2.3. Design. There were three IVs in this experiment: Grammaticality (grammatical, ungrammatical); inflection (past tense, third person, plural) and speed of stimulus presentation (baseline, 30% slower). As with the other experiments in this thesis, the dependent variable was the reaction times to the target words in the word monitoring task.

This experiment used a within-subjects design. All children experienced both grammaticalities (grammatical and ungrammatical), all three inflections (past tense, third person, plural) and both speeds (normal baseline and 30% slower-than-baseline).

6.2.4. Procedure. Children were seen within the language unit during their usual session times on a one-to-one basis. Fully informed consent was gained from each child's main caregiver, mainstream primary school teacher and language unit teacher.

All children who had consent were seen for three separate testing sessions, each one week apart. On the first testing session, the standardised measures were given as a screener to assess whether the children fitted this study's diagnostic criteria for SLI. This session lasted approximately one hour. The children who 'passed' the screener were then seen for two further sessions, each lasting approximately 20 minutes. On the second testing session children completed the basic auditory reaction time task and one word monitoring task, either at a baseline or slow speed. On the final testing session, children completed the flanker task and another word monitoring task at the remaining speed. Table 24 clarifies the procedure and counterbalancing.

Child number	Session 1 (screener)	SLI?	Session 2 (word monitoring task and baseline reaction time task)	Session 3 (word monitoring task and flanker task)
1	All standardised tests outlined in table 23	No	-	-
2	All standardised tests outlined in table 23	Yes	Baseline set A	Slow set B
3	All standardised tests outlined in table 23	Yes	Baseline set B	Slow set A
4	All standardised tests outlined in table 23	Yes	Slow set A	Baseline set B
5	All standardised tests outlined in table 23	Yes	Slow set B	Baseline set A

Table 24. Example testing schedule for Experiment 4.

6.3. Results

6.3.1. Data Preparation. As with all experiments in this thesis, participant reaction times to the target words were calculated by subtracting the position of the target word from the overall reaction time for that sentence (see section 3.3.1 for details). Also analogous to the other experiments in this thesis, false data points and non-responses were removed and replaced with the mean for that word class and grammaticality (see section 3.3.1 for details). Finally, reaction time data were log-transformed due to skew, as recommended by Ratcliff (1993). All reaction time analyses for this experiment are based upon log-transformed data, unless otherwise stated.

6.3.2. Word monitoring task

6.3.2.1 Accuracy. There was a reasonable amount of non-responses and false alarms (responses before the target word) in both the baseline and slow conditions of this experiment, with more errors made when the sentence articulation rate was slowed. Any 'inaccurate' data points on the basis of non-response or false alarm were removed from the data set and replaced by the mean score based on all valid data points for that grammaticality and word class (as per the procedure detailed in section 3.3.1). Overall, for the baseline condition, 1.45% of responses were removed on the basis of no-response and 9.44% were removed because children pressed the button before the target word occurred. For the slow-rate condition, 1.17% of responses were non-responses and 13.30% were false alarms.

The mean number of errors (false alarms + non-responses) in the baseline condition was 5.278 (SD=2.052), and in the slow-rate condition was 6.944 (SD=2.182). Scores were out of a possible 48. A paired-samples t-test revealed that more errors were made in the slow-rate condition, as compared to the normal-rate, baseline condition ($t(17)=-2.73$, $p=.014$).

A bivariate Pearson's correlation was conducted to assess whether there was a speed-accuracy trade-off. That is, were children more likely to make errors when they responded quickly? Results indicated that there was no speed-accuracy trade-off in either speed condition. There was no significant relationship between raw reaction times in the baseline word monitoring task (mean raw reaction time 1397.89ms, SD 504.35ms) and the number of errors made ($r=.144$, $p>.05$). Similarly, there was no significant relationship between reaction times in the slow-rate word monitoring task (mean raw reaction time 2561.68ms, SD 683.16ms) and the number of errors made ($r= -.069$, $p>.05$).

6.3.2.2 Grammatical sensitivity. The overall mean reaction times to the target words are presented in table 25, separated out by speed, grammaticality and inflection (both raw and log-transformed data are presented for transparency).

Speed	**Inflection**	**Grammaticality**	**Raw RT (SD)**	**Log RT (SD)**
Baseline	Plural	Grammatical	1302 (650)	3.121 (0.234)
		Ungrammatical	1409 (457)	3.129 (0.138)
	Third Person	Grammatical	1453 (598)	3.128 (0.258)
		Ungrammatical	1562 (569)	3.167 (0.157)
	Past Tense	Grammatical	1339 (515)	3.155 (0.190)
		Ungrammatical	1518 (591)	3.147 (0.185)
Slow	Plural	Grammatical	2373 (2182)	3.234 (0.373)
		Ungrammatical	2590 (2385)	3.360 (0.344)
	Third Person	Grammatical	2396 (2390)	3.201 (0.443)
		Ungrammatical	2783 (2353)	3.326 (0.347)
	Past Tense	Grammatical	2682 (2476)	3.292 (0.364)
		Ungrammatical	2637 (2380)	3.303 (0.323)

Table 25. Mean reaction times to the target words in the baseline and slow-rate word monitoring task (exp 4)

A 2 (speed: baseline, slow) x 3 (inflection: plural, third person, past tense) x 2 (grammaticality: grammatical, ungrammatical) repeated-measures ANOVA was conducted on the log-transformed data. There were main effects of speed ($F(1,16)=6.91$, $p=.02$), inflection ($F(2,32)=3.39$, $p=.046$) and grammaticality ($F(1,16)=10.91$, $p=.004$). In addition, there were significant speed*inflection ($F(2,312)=3.69$, $p=.036$), speed*grammaticality ($F(1,16)=5.44$, $p=.033$) and speed*inflection*grammaticality ($F(2,32)=4.64$, $p=.017$) interactions. The interaction between inflection*grammaticality was nonsignificant ($F(2,32)=.61$, $p>.05$). Given the complexity of the results, each speed will be analysed in turn.

6.3.2.2.1. Baseline performance. A 2 (grammaticality: grammatical, ungrammatical) x 3 (inflection: plural, third person, past tense) repeated measures ANOVA was conducted on the log-transformed baseline (normal speed) word monitoring task reaction times. There was no main effect of grammaticality ($F(1,16)=5.88$, p=>.05), nor was there a main effect of inflection ($F(2,32)=4.50$, $p>.05$). In addition, there was no significant grammaticality*inflection interaction ($F(2,32)=.46$, $p>.05$). These results can be seen graphically in figure 16. The figure and statistics indicate that children treated all sentences the same i.e. they responded with equal speed, regardless of the word class of the preceding item in the sentence. This is in contrast to the 'typical' word monitoring task finding, which demonstrates that nouns are responded to faster than verbs.

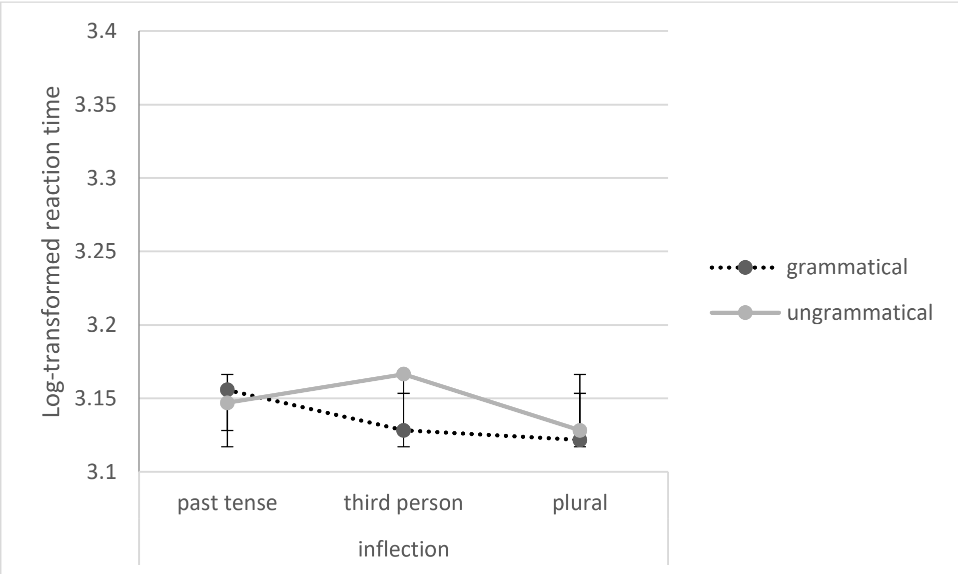


Figure 16. Log transformed reaction times by children with SLI to sentences presented at a normal rate, as a function of grammaticality and inflection. Error bars represent standard error (exp 4). *NB: T-tests revealed non-significant differences between the grammatical and ungrammatical constructions for each inflection.*

6.3.2.2.2. Slow-rate performance. A 2 (grammaticality: grammatical, ungrammatical) x 3 (inflection: plural, third person, past tense) repeated measures ANOVA was conducted on the log-transformed slow-rate word monitoring task reaction times. There was a main effect of grammaticality, such that targets following a grammatical critical word were responded to faster (mean raw RT

2484ms mean raw SD 2349ms, mean log RT 3.242ms mean log SD .393ms) than targets following an ungrammatical critical word (mean raw RT 2670ms, SD 2373ms, mean log RT 3.329ms, mean log SD .338ms) ($F(1,16)=5.47$, p=.033). There was no main effect of inflection ($F(2,32)=2.27$, p>.05), but there was a significant grammaticality*inflection interaction ($F(2,32)=4.88$, p=.014). These results can be seen graphically in figure 17. The graph indicates that whilst children were sensitive to grammaticality when targets followed a third person singular and a plural inflection (represented by a relatively a large gap between the lines), they were less sensitive to the grammaticality when the target followed a regular past tense construction (no gap between the lines).

Figure 17. Log tnsformed reaction times by children with SLI to sentences presented at a slow rate, as a function of grammaticality and inflection. Error bars represent standard error (exp 4). *NB: * denotes t-test significance at the .016 level, adjusted for familywise error rates.*

6.3.3. Comparisons with age-matched participants. This experiment only tested children with SLI. Whilst some interesting results have been found, it would be valuable to compare the data from children in this experiment with children of the same age from other experiments within this thesis. As this is the only experiment in the thesis with a slow-rate condition, it is only possible to directly compare word monitoring task performance at a normal-rate (baseline) speed. Children have been selected from experiment 3 as the sample most closely matches the current sample with regards to age and standardised measures administered. In addition, the word monitoring task in the current experiment was identical to that used in experiment 3, and so direct comparisons can be made with no concern regarding methodological differences. Children were matched, case-by-case, based on chronological age (age matches were performed ± 3 months). A total of 12 children from the current experiment were able to be matched on these grounds, the details of which are presented in table 26.

Group	**Age in months (SD)**	**CELF-IV Expressive Vocabulary (/54)**	**CELF-IV Word Structures (/32)**	**WISC Block Design (/68)**	**Basic auditory RT (SD)**	**Flanker task conflict effect (SD)**
Typically Developing	104.91 (3.75)	23.33 (2.67)	25.67 (2.84)	31.16 (3.38)	370(154)	154.92 (100.82)
SLI	102.25 (3.84)	19.17 (4.71)	15.92 (4.62)	28.83 (4.92)	479 (169)	117.42 (154.44)

Table 26. Standardised test scores for the SLI and age-matched group (exp 4)

A series of independent-samples t-tests revealed that the two groups of children were matched on age (*t(*22)=1.72, p>.05) and nonverbal (block design) ability (*t(*22)=-1.03, p>.05). The analyses revealed significant differences (with the SLI group always scoring more poorly than the typically-developing group) in the CELF-IV expressive vocabulary (*t(*22)=-2.67, p=.014), the CELF-IV word structures (*t(*22)=-6.23, p<.001), the basic auditory reaction time task (*t(*22)=4.89, p<.05) and the Flanker task (*t(*22)=-4.28, p=<.05).

6.3.3.1 Comprehension question accuracy. Each sentence in the word monitoring task was followed by a comprehension question. An independent-samples t-test was conducted, comparing the number incorrect answers given by the SLI group with the number of incorrect answers in the typically developing group.

The scores were out of a possible 48. The results showed that children with SLI gave more incorrect answers (mean 5.58 errors, SD 2.64) than the typically-developing children (mean 2.25 errors, SD 1.28) ($t(22)=3.93$, $p=.001$).

6.3.3.2 Word monitoring task accuracy and speed. The children in the SLI group performed with less accuracy and speed in the word monitoring task, as compared to the typically-developing control children. The mean number of errors (false alarms + non-responses out of a total of 48) was 4.99 (SD 2.12) for the SLI group and 2.60 (1.51) for the control group. The mean reaction time to the target words in the word monitoring task was 1360.33ms (SD 101.89ms, log RT, SD) for the children with SLI, and 623.49ms (SD 396.61ms, log RT, SD) for the typically-developing children. The worse performance from the SLI group was significantly worse than that of the control group, according to paired samples t-tests (both $p<.05$).

6.3.3.3 Word monitoring task grammatical sensitivity. A 2 (group: typically developing, SLI) x 2 (grammaticality: grammatical, ungrammatical) x 3 (inflection: past tense, third person singular, plural) mixed design ANOVA was conducted on the log-transformed word monitoring task data. Results showed a main effect of group ($F(1,22)=16.98$, $p<.001$), with the SLI group responding to the target words slower (mean RT 1464ms, SD 619ms, log RT 3.217ms, SD 2.792ms) than the typically-developing group (mean RT 623ms, SD 520ms, log RT 2.795ms, SD 2.716ms).

The analyses also showed a main effect of grammaticality ($F(1,22)=28.10$, $p<.001$), with targets following grammatical constructions being responded to faster (mean RT 914ms, SD 543ms, log RT 2.961ms, SD 2.735ms) than targets following ungrammatical items (mean RT 1174ms, SD 596ms, log RT 3.069ms, SD 2.775ms). There was a main effect of inflection ($F(2,44)=3.37$, $p=.044$), with post-hoc tests showing that the targets following past tense constructions were responded to slower (mean RT 1255ms, SD 605ms, log RT 3.098ms, SD 2.782ms) than third person singular constructions (mean RT 1043ms, SD 541ms, log RT 3.018ms, SD 2.733ms) ($p=.002$) and plural constructions (mean RT 978ms, SD 552ms, log RT 2.990ms, SD

2.742ms) (p<.001). The targets following third person singular inflections were, in turn, responded to slower than those following plural constructions (p=.048). As expected, there was a significant inflection*group interaction ($F(2,44)=4.65$, p=.015), which can be seen graphically in figure 18. The figure suggests that whilst the typically-developing children responded to the target words in the 'classical' manner (i.e. targets following plurals were responded to fastest, followed by the third person singular, followed by the past tense), the children with SLI had very similar reaction times across all three inflections.

There were nonsignificant interactions between inflection*grammaticality ($F(2,44)=3.04$, p>.05), grammaticality*group ($F(1,22)=.57$, p>.05) and inflection*group*grammaticality ($F(2,44)=1.88$, p>.05).

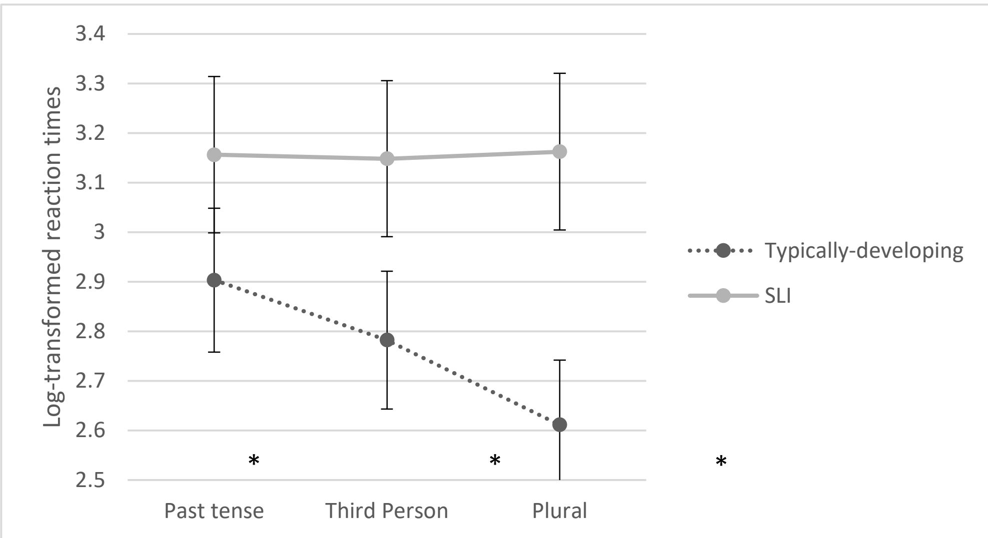


Figure 18. Reaction times to the target words by the SLI and age-matched groups, as a function of inflection. Error bars represent standard error. *NB: * denotes t-test significance at the .016 level, adjusted for familywise error rates*

6.3.3.3.1 Comparing slow-rate SLI with normal-rate controls. The rationale for slowing the sentence presentation rate down for children with SLI was to assess the impact this has on grammatical performance, relative to typically-developing children. That is, does the grammatical performance of children with SLI in the slow-rate condition 'look' like that of typically-developing children in the normal-rate condition? In order to statistically analyse these data, a single metric is required that represents 'grammatical performance in the word monitoring task' for both the

SLI and control children. This metric was a raw difference score, representing the grammatical-ungrammatical discrepancy (see chapter 7 for further discussions on this metric). The magnitude of the difference relates to the degree of grammatical sensitivity: a large difference score between grammatical and ungrammatical reaction times implies strong grammatical sensitivity, whereas a small difference score suggests a lack of inflectional processing (see chapter 2 for further details).

A 2 (group: SLI, typically-developing) x 3 (inflection: past tense, third person singular, plural) mixed ANOVA was conducted on the raw difference scores. There was a main effect of inflection ($F(2,44)=4.44$, $p=.018$), with Pairwise comparisons revealing a significant difference between the past tense and the plural difference scores ($p=.036$). There was no main effect of group ($F(1,22)=1.53$, $p>.05$), however there was a significant inflection*group interaction ($F(2,1)=7.48$, $p=.012$), which can be seen in figure 19. As it can be seen, it appears that the two groups differ substantially on their grammatical performance for the regular past tense items, but not for the third person singular and plural items.

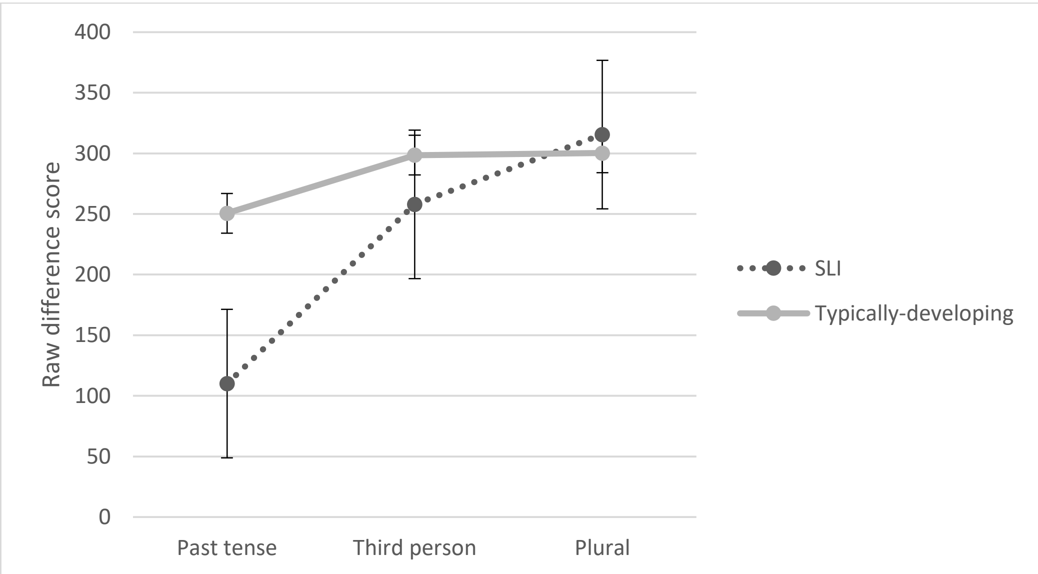


Figure 19. Grammatical sensitivity (as represented by grammatical-ungrammatical difference scores) for the SLI-slow and typically-developing-normal rate conditions, as a function of inflection. Error bars represent standard error (exp 4).

6.4. Discussion

The rationale for this experiment was a culmination of the first three experiments of this thesis. Collectively, the findings from experiments one, two and three suggested that the specific pattern of inflectional difficulties seen in children with SLI may be the result of a deficit in the speed with which normal-rate language can be processed. This conclusion derived from data that showed: a) typically-developing children could demonstrate SLI-like inflectional impairments in an online word monitoring task when cognitive load stressed their speed of processing (the speed of stimulus presentation was increased) and b) this effect appeared to be unique to speed; neither noise nor length stressors induced a similar effect. It was suggested that in order to fully test this hypothesis, one could examine whether the inflectional impairments in SLI could be alleviated by slowing sentence presentation rate down, and thus 'reversing' the paradigm and giving children more time to processing the incoming information.

However, this 'slowing down' experiment would only work, on a theoretical level, if the children with SLI demonstrated specific inflectional deficits in the word monitoring task under normal/optimum listening conditions. Whilst it has been well-established that children with SLI are generally slower to respond to the target words in the word monitoring task (Montgomery & Leonard, 2006), and that they show a hierarchy of inflectional difficulty in naturalistic language (e.g. Rice & Oetting, 1993) and grammaticality judgement tasks (e.g. Hayiou-Thomas, Bishop & Plunkett, 2004), it has not yet been established whether children with SLI show their specific pattern of inflectional difficulty in an online measure.

In view of the points raised above, the current experiment had two main aims. Firstly, it wanted to establish whether children with SLI demonstrated their 'classical' pattern of inflectional hierarchy when their inflectional processing skills were measured by an online word monitoring task. Secondly, this study sought to explore whether any online grammatical difficulties seen in SLI could be alleviated by 'lightening the load', by way of slowing down the speed of stimulus presentation.

The data showed some interesting results. With regards to the first aim of this experiment, children did **not** show their inflectional hierarchy of difficulty in the word monitoring task when sentences were presented at a normal, conversational rate. Rather, they responded with equal speed across all three inflections (regular past tense, third person singular, regular plural). In fact, their performance looks to be close to floor in this baseline condition. This finding is at odds with what is seen in the naturalistic language and offline grammatical processing skills of children with SLI, and with what is seen in typically-developing populations (as evidenced by the findings in the experiments one and two of this thesis). Perhaps the time demands and complexities of the word monitoring task were simply too great when sentences were presented at a normal rate.

This postulation is supported by the data from the slow condition in this experiment. Here, when children with SLI were given more time to process the incoming information by way of slowing the speech signal down, they did show an improvement in overall grammatical sensitivity (i.e. the gap between the bars increased), and the hierarchy of inflectional difficulty. That is, the regular past tense was the most impaired, and the regular plural inflection was the least impaired, in terms of grammatical-ungrammatical reaction time discrepancy.

Interestingly, slowing the speech signal down did not improve the past tense sensitivity of the children with SLI, relative to the normal speed condition, although it did for both the third person singular inflection and the regular plural inflection. This could be because the rate wasn't slow enough, although from looking at the data, there is no indication that sensitivity to the regular past tense was even beginning to improve, so this explanation is unlikely. Alternatively, it may be because this is one of the most difficult inflections for children learning English to master, due to its weak phonological saliency and the grammatical complexity (cf. Chiat, 2000). As such, the children with SLI may have such an entrenched impairment with this particular inflection, that a simple short-term 'lightening of the load' may not be enough. Instead, children with SLI may require repeated presentation of slow-rate language, alongside help with learning to process language in a more time-effective manner, before the deficit in the regular past tense starts to lessen. Indeed, the suggestion that the regular past tense deficit is extremely deeprooted is supported by studies showing impairments in this to be a hallmark of SLI (see Conti-Ramsden, 2003)

6.4.1. Theoretical implications and future directions. This study carries some very important theoretical implications. Firstly, this study has been the first to establish that children with SLI may not show the classical hierarchy of inflectional difficulty, when this skill is measured by an online task, although they do show an overall sensitivity to grammaticality (regardless of inflection type). It was argued that this may be because grammatical processing is a two-step process, in which the overall grammaticality of a sentence is processed, before moving on to detect exactly where any ungrammaticality may lie. This notion needs further testing, in order to establish its validity. Further research is also needed that attempts to replicate the (novel) finding that children with SLI do not show an inflectional hierarchy of difficulty when inflectional awareness is measured by an online word monitoring task.

In addition, the results of this experiment go some way in supporting the view that the specific inflectional difficulties in SLI are the result of a deficit in speed of processing. At the most fundamental level, the basic auditory reaction times and overall word monitoring task reaction times of children with SLI were slower than the typically-developing controls. This indicates that there may be some level of 'generalised slowing' (e.g. refs) in children with SLI. In addition, it was found that the inflectional sensitivity of children with SLI could be improved with regards to the third person singular and regular plural inflections when sentence presentation rate was slowed down. This gives some indication that the impairment in speed of processing plays a causal role in the inflectional difficulties in children with SLI. However, this improvement this was not shown in the regular past tense inflection, which remained impaired even in the slow-rate condition. It has been suggested that this is because the deficit in the regular past tense is extremely deep-seated, and a simple short-term slowing of language input rate is not enough to overcome the difficulties that are so entrenched in children with SLI.

Although this study made some attempt to compare the performance of the children with SLI with typically-developing children, it falls somewhat short in this aspect. The control children were taken from a different experiment in this thesis, and although the stimuli were the same and the ages were matched, it is felt that the design would have been neater if the typically-developing participants formed part of the same experiment. In addition, a language-matched control group would have further strengthened this design. By including this type of control group, conclusions could be drawn regarding the deficit in SLI, relative to their general language weaknesses. At present, it is not known if the difficulties children with SLI had in this experiment are because of their general language weaknesses, or if they are in spite of this. In addition, question of whether children with SLI are delayed or deviant with regards to their speed of processing and language skills could be addressed if a language-matched group was included.

6.4.2. Summary. The findings of this experiment suggest that the inflectional difficulties of children with SLI may indeed be mediated by a speed of processing deficit, and that grammatical processing may be a two-step process which is mediated by speed of processing skills. The real-time inflectional impairments in the children with SLI could be somewhat alleviated by slowing the sentence presentation rate down, although deficits in the regular past tense remained, despite the children having more time to process the incoming speech signal. It is suggested that this may be because deficits in the regular past tense are extremely ingrained in children with SLI, and so a simple short-term fix (i.e. temporarily slowing down the speech signal) is not enough. This inordinate difficulty with the regular past tense is possibly as a result of the weak phonological salience, coupled with the grammatical complexity of the morphological item, in everyday language. These findings and conclusions are rather speculative at present, and further replication work is needed, which should include both age- and language-matched control groups.

Chapter 7. The Mechanisms of the Word Monitoring Task

The word monitoring task was used throughout this thesis as a measure of online inflectional processing skills. It was felt that this was one of the 'purest' reflections of grammatical processing in everyday language situations, that was free of working memory and metalinguistic confounds (see section 1.2 and chapter 2 for full justification).

The word monitoring task is a relatively new paradigm, and the mechanisms that one calls upon when performing the task are as yet unknown. Whilst it has been championed as an effective measure of general language processing and inflectional awareness (e.g. Mongtomery & Leonard, 2006; Tyler, 1992), there is no evidence to date that demonstrates whether or not children call upon *linguistic* knowledge to perform this task. The only requirement of the task is to respond to the target word. In the grammaticality judgement task for example, children have to process the whole sentence in order to decide if it was grammatically well-formed or not. There is no such reasoning in the word monitoring task; the only requirement of the task is to respond to the target word. It seems possible therefore that the word monitoring task may not rely on linguistic knowledge per se, rather it may be mediated by more non-linguistic cognitive domains, such as attention.

In addition, participants are not given a strategy in the word monitoring task. That is, they are not asked to process the whole sentence, nor are they asked to disregard the non-target words. The exact approach that people adopt when performing a word monitoring task is not known. It is unclear whether people just listen out for the target word and disregard all non-target items, or whether they process the entirety of the sentence.

Each experiment in this thesis included a variety of standardised measures which spanned a wide range of linguistic and non-linguistic domains. Scores on these measures could be correlated with performance on the word monitoring task in an attempt to explore what skills children drew upon when completing the task. In addition, experiments two, three and four of this thesis included comprehension questions, which were intended to help answer the question of what strategy people were taking when they completed the word monitoring task: were they *just* listening out for the target word (and thus would have poor comprehension scores), or were they processing the whole sentence?

One question that needed to be resolved before the correlation analyses could take place relates to the metric used for the word monitoring task variable. In the word monitoring task, each participant receives two overall scores: mean reaction time to grammatical constructions and mean reaction time to ungrammatical constructions. Clearly, correlation analyses cannot be conducted on these two data points as they stand, and so a single metric needed to be established that accurately represented a child's *performance* in the word monitoring task.

Several metrics were considered, which included: calculating the raw grammatical-ungrammatical difference score; calculating the raw grammatical-ungrammatical difference score and dividing this by the overall mean reaction time (in an attempt to control for individual differences); and calculating an effect size for each participant. It was decided that the metric used for all correlation analyses would be the raw grammatical-ungrammatical difference score (hereafter referred to as word monitoring task performance). This is because a) this is the metric that is recommended by Tyler (1992), a leading researcher in the word monitoring task paradigm and b) theoretical parallels can be drawn between the word monitoring task and the Flanker task (discussed in chapter 2), which also uses a raw difference score (in this case between congruent and incongruent trials) as the outcome measure. With this word monitoring task performance metric, worse performance is associated with a smaller difference score, and thus less sensitivity to grammaticality within the sentences (cf. Montgomery & Leonard, 2006).

The nature of the standardised measures and the comprehension questions evolved over the series of experiments in this thesis, in response to results and new predictions. As such, each experiment will be discussed in turn, with reference to the underlying mechanisms mediating performance in the word monitoring task. First though, the reliability of the word monitoring task will be addressed.

7.1. Test retest reliability of the word monitoring task

Although the word monitoring task is becoming an increasingly popular paradigm in language research, the mechanisms surrounding it are not well understood, and there is little-to-no research investigating this. The correlation analyses in this chapter have been carried out in an attempt to explore the skills that underlie performance in the word monitoring task, and the comprehension questions have been analysed to try and understand the strategies adopted when completing a word monitoring task. In addition to the underlying mechanisms and the strategies adopted, the reliability of the word monitoring task is also unknown. To my knowledge, no research has explored the stability of scores on the word monitoring task over time.

With this in mind, 20 children from the baseline condition in Experiment 2 were given the same word monitoring task 3 months after the first session. Scores from time 1 were correlated with time 2 to assess the test-retest reliability of the task. At time 1, the mean overall reaction time (raw, collapsed across word classes and grammaticality) was 586.69ms (SD 180.56ms). At time 2 the mean overall reaction time (raw, collapsed across word classes and grammaticality) was 540.68ms (SD 98.94ms). The correlation between the two time-points was extremely strong ($r=.759, p<.001$), suggesting that scores on the word monitoring task are stable over time.

7.2. Experiment 1

Experiment 1 measured linguistic and grammatical skills using the Core Language Score from the CELF-IV. This Core Language Score was a composite measure, composed of the following subtests:

- Concepts and Following Directions
  - Assesses syntactic and metalinguistic skills
- Word Structure
  - Measures morphological ability
- Recalling Sentences

  - Measures syntactic and metalinguistic skills, as well as verbal short term memory
- Formulated Sentences
  - Measures syntactic and semantic skills

Experiment 1 also measured nonverbal ability using the Matrices and Quantitative Reasoning subtests from the BAS II. These both measured inductive reasoning skills.

Chapter 2 details these standardised measures in more depth.

A Pearson's correlation analysis was conducted on the data, entering the raw scores in the standardised measures, word monitoring task performance, basic auditory reaction time and age as variables. Each of the four speeded conditions (0%, 10%, 20%, 30%) were analysed separately, because it may have been the case that children drew upon different skills when the task was more challenging, as compared to when the task was presented at baseline levels. Collapsing across speeded conditions would not allow this to be examined.

Table 27 details the correlation coefficients between the various measures and word monitoring task performance at each of the four speeded conditions. As it can be seen, there were no significant correlations between word monitoring task performance (at any speed) and any standardised measure (all $p>.05$). In addition, age was not related to word monitoring task performance ($p>.05$). However, basic auditory reaction time did have a weak-moderate, significant negative correlations with word monitoring task performance at all four speeded levels, indicating that the slower a child was at responding to basic auditory tones, the less successful they were in the word monitoring task. That is, they were less sensitive to the grammaticality within sentences.

There are three possible reasons as to why there were no significant correlations between word monitoring task performance and the standardised measures in this experiment. Firstly, it may have been that that the wrong metric was used for the word monitoring task data. However, the rationale behind using the raw difference score seemed sound (it was suggested by Tyler (1992), and the task draws parallels with the Flanker task, which also uses raw difference scores as its metric). In addition, subsequent exploratory analyses were conducted on the 'word monitoring task performance/RT' and 'effect size' metrics outlined earlier, and no correlations were found either. This further confirms that the metric used was the most appropriate choice.

The second reason may simply have been that the nature of the measures used in this study meant that they did not genuinely correlate with on-line inflectional processing, as measured by the word monitoring task at least. The standardised tests that comprised the initial screening in this study were all measures of off-line skills: The CELF-IV language measures all require a child to listen to information, process it and then respond. The BAS-II nonverbal tests used in this study also allow a child to reflect and think strategically before answering. It may be that a more on-line skill drives task performance in the word monitoring paradigm, given that it is an online measure.

Thirdly, it may be the case word monitoring task performance is driven by a domain that was not assessed in this first study. This present study assessed language and nonverbal IQ skills. The word monitoring task requires a child to hold the target word in their mind whilst listening to the sentence. The child must selectively attend to the target word, whilst ignoring all other words within the sentence. In this sense then, it seems possible that it may be attention driving performance, rather than language and/or nonverbal IQ skills. Likewise, the word monitoring task is a speeded measure, and so perhaps performance in mediated by speed of processing. Indeed, the only significant correlation from this experiment was between word monitoring task performance and basic auditory reaction times. In view of this, it was felt that including attention measures and further speed of processing measures in the test battery of future studies would be beneficial, and would allow further investigations in to what might mediate word monitoring task performance.

In view of these results, it is as yet unclear what factors drive performance in the word monitoring task. In addition, it is unclear what the children's strategy is when performing a word monitoring task. Although children were asked to listen out for the target word, it is unknown whether they were doing this *and* processing the sentence's content (i.e. comprehending it), or whether they were disregarding the content and are just listening out for the target word. Including comprehension questions in subsequent experiments would provide some insight into the strategies children might adopt when completing a word monitoring task.

	Baseline	**10%**	**20%**	**30%**
Concepts and Following Directions	-.28	-.14	.21	.28
Word Structure	.14	.11	.22	-.26
Recalling Sentences	-.23	-.29	-.14	.14
Formulated Sentences	.15	.28	.16	.20
Matrices	.18	-.16	-.25	.21
Quantitative Reasoning	-.20	.11	-.21	-.17
Age	-.21	-.12	.16	.19
Basic auditory RT	-.33**	-.38**	-.22*	-.29*

Table 27. Correlations between measures given to children and word monitoring task performance. ***p<.05 ***p<.01** (exp 1)

7.3. Experiment 2

The results from Experiment 1 gave rise to the addition of standardised speed of processing and attention measures in the test battery for this experiment, as well as comprehension questions. Two attention measures were taken from the TEA-Ch: The Map Mission measured selective/focussed attention and the Walk/Don't Walk subtest measured sustained attention and response inhibition. In addition, the WISC-IV Symbol Search subtest was included in this experiment, which is a measure of processing speed and concentration. Finally, standardised vocabulary (BPVS-3), grammar (TROG-II) and nonverbal (Block Design) measures were administered (see chapter 2 for a detailed overview of all standardised tests).

A comprehension question was asked after each sentence to see whether children were processing the sentence content or not. There were 40 individual sentences used in the word monitoring task of this experiment, and so there were 40 comprehension questions in total (see Appendix A).

A Pearson's correlation analysis was conducted on the data, entering raw scores for all standardised tests, basic auditory reaction time, age and word monitoring task performance as variables. As with the analyses for Experiment 1's data, each of the conditions (baseline, long sentences, 30% speeded, multi-talker babble noise mask, signal-correlated noise mask) were analysed separately, in order to examine whether different skills mediated performance in different types of stressors.

NB: For the purposes of succinctness, only significant correlations will be discussed.

7.3.1. Baseline condition. As with Experiment 1, there was a strong negative correlation between basic auditory reaction time and word monitoring task performance ($r = -.582$, $p=.006$), such that as children's reaction times got slower (increased), their performance in the word monitoring task got worse (difference score decreased). In addition, performance on the Walk-Don't Walk task (a measure of response inhibition and sustained attention) bore a moderate, negative correlation to word monitoring task performance ($r=-.507,p=.019$). This suggests that as response inhibition ability increased (improved), performance on the word monitoring task improved. There were no other notable correlations.

7.3.2. Signal-correlated noise mask. As with the baseline condition, there was a strong negative correlation between basic auditory reaction time and word monitoring task performance ($r = -.630$, $p=.003$), such that as children's reaction times got slower (increased), their performance in the word monitoring task got worse (difference score decreased). Interestingly, as with the baseline condition, the correlation between scores on the Walk-Don't Walk task were again negatively correlated with word monitoring task performance ($r=-.474, p=.035$), indicating that children who were better at selective attention were better in the word monitoring task. For this condition, scores on Symbol Search (a measure of processing speed) were also moderately related to mean word monitoring task reaction times ($r=.483, p=.031$), such that the faster a child could find a target symbol in an array of other symbols, the faster they tended to respond to the target word in the word monitoring task.

There were no other notable correlations.

7.3.3. Multi-talker babble noise mask. In this condition, the word monitoring task performance only appeared to correlate negatively with basic auditory reaction time ($r=-.406, p=.027$). That is, the more sensitive a child was to grammaticality in the word monitoring task, the faster they responded to basic auditory tones. Interestingly, no other variables were even close to correlating.

7.3.4. Long sentences. As with most stressors in this experiment, and Experiment 1 of this thesis, there was a moderate negative correlation between basic auditory reaction time and word monitoring task performance ($r = -.481$, $p=.048$), such that as children's reaction times got slower (increased), their performance in the word monitoring task got worse (difference score decreased). In addition, performance on the Walk-Don't Walk task (a measure of response inhibition and sustained attention) bore a weak, negative correlation to word monitoring task performance ($r=-.301, p=.019$). This suggests that as response inhibition ability increased (improved), performance on the word monitoring task improved. Finally, performance on the Symbol Search task was moderately related to mean word monitoring task reaction times (r=.422,p=.039), such that the faster a child could find a target symbol in an array of other symbols, the better they tended to perform in the word monitoring task.

7.3.5. 30% speeded sentences. In this condition, there was a strong negative correlation between word monitoring task performance and basic auditory reaction time (r =.601, p = .011). There was also a moderate negative correlation between word monitoring task performance and scores on the Walk-Don't Walk task (r = -.503, p= .025). Finally, there was a strong positive correlation between word monitoring task performance and Symbol Search (r = .616, p = .001), such that the faster a child could find a target symbol in an array of other symbols, the better they tended to perform in the word monitoring task.

7.3.6. Comprehension question performance. Related to the question of what exactly mediates performance in the word monitoring task, there is the question of what are children actually *doing* in the task? Do they only listen for the target and therefore disregard the semantics of the sentence, or are do they process the sentence as a whole? This second experiment included a comprehension question after each sentence to try to assess this. Performance on these questions was at ceiling for each of the five groups; almost all children scored a maximum score of 40/40, regardless of cognitive stress (see table 28). Because of this ceiling performance, analyses could not be conducted without serious confound.

Group	Mean score (SD) on comprehension questions /40
Baseline	38.25 (1.05)
Signal-correlated noise	37.95 (1.27)
Multi-talker babble noise	38.00 (1.35)
30% speeded condition	38.10 (1.10)
Long sentences	39.01 (0.95)

Table 28. Mean scores on comprehension questions (and SD) for each of the five conditions (experiment 2).

7.3.7. Summary of experiment 2. The results from this experiment are more encouraging than the results from experiment 1, and give some indication as to the mechanisms that underlie performance on the word monitoring task. Specifically, it seems that the word monitoring task may indeed be mediated by the non-linguistic domains of attention and speed of processing, rather than more specific language skills, or nonverbal intelligence. The Walk-Don't Walk task seemed to correlate well with word monitoring task performance across several of the conditions. This task is a measure of sustained attention and response inhibition. It is therefore unsurprising in some respects that this measure correlated with word monitoring task performance, as to score well in the word monitoring task, one needs to focus on the target word (sustained attention) and only respond when that target word is heard (response inhibition). In addition, the standardised measure of speed of processing, Symbol Search, correlated well with word monitoring task performance in several conditions. Again, this is relatively unsurprising, given that both the word monitoring task and the Symbol Search task are dependent upon speeded response.

There did not appear to be differential patterns of correlating variables across the various stressors. That is, no matter what the cognitive stressor was, children appeared to call upon the same non-linguistic attention and speed of processing skills.

7.4. Experiment 3

This experiment included the Flanker task in its test battery (see 2.3.5.1 for a detailed description), which was expected to show strong correlations with word monitoring task performance, given the theoretical parallels (see chapter 2). The metric used in the correlations for the Flanker task was the 'conflict effect' (see section 2.3.5.1), with a larger conflict effect representing better performance. The three signal-to-noise ratios were collapsed for these analyses, as they did not have significant main effects in either the multi-talker babble noise mask or the signal-correlated noise mask. As such, there are three noise type 'conditions' to discuss for this experiment: baseline, multi-talker babble and signal-correlated noise.

For all three noise type conditions in this experiment, the effects were the same: There were significant negative correlations between basic auditory reaction time and word monitoring task performance in the baseline ($r = -.477$, $p = .034$), multi-talker babble ($r = -.287$, $p = .041$) and signal-correlated noise ($r = -.301$, $p = .033$) conditions. In addition, the magnitude of the conflict effect in the Flanker task correlated positively with word monitoring task performance in the baseline ($r = .588$, $p = .012$), multi-talker babble ($r = .299$, $p = .039$) and signal-correlated noise ($r = .411$, $p = .02$) conditions, such that the better a child was in the Flanker task, the better they were in the word monitoring task.

There were no other notable correlations.

This experiment also included comprehension questions after the stimuli items, but the questions were more difficult than in Experiment 2, given the ceiling performance of the participants in that study.

Table 29 outlines the mean comprehension scores out of a possible 48 for each of the conditions. Although there was a trend towards comprehension question accuracy reducing in the more difficult (i.e. noisier) conditions, there was a nonsignificant effect of stressor in the one-way ANOVA ($p>.05$).

As with Experiment 2, the accuracy rates for the comprehension questions were extremely high, with even the most difficult condition (-8dB MTB) showing over 85% of the comprehension questions being answered correctly. This lends further support to the notion that, when performing a word monitoring task, children are indeed listening to the whole sentence, rather than just listening out for the target word.

Condition	**Mean score (SD) on comprehension questions /48**
Baseline	46.25 (2.05)
0dB Multi-talker babble	45.95 (1.89)
-4dB Multi-talker babble	44.85 (1.75)
-8dB Multi-talker babble	41.10 (3.10)
0dB signal-correlated noise	46.04 (1.85)
-4dB signal-correlated noise	46.74 (2.06)
-8dB signal-correlated noise	44.01 (1.99)

Table 29. Mean scores on the comprehension questions in the word monitoring task for each of the conditions (experiment 3).

7.5. Experiment 4

This experiment was different to the others in this thesis, as it was the only one to use a sample of children with SLI. It has been shown so far that: a) typically-developing children call upon their non-linguistic attentional and speed of processing skills in order to complete the word monitoring task effectively and b) children do indeed process the whole sentence in the word monitoring task, rather than just listening out for the target word and disregarding the semantics of the sentence.

Although the children in this experiment had weaker language skills than the typically-developing participants of the other experiments, the same factors were associated with performance in the baseline word monitoring task. That is, word monitoring task performance correlated moderately and negatively with basic auditory reaction time ($r = -.436$, $p=.048$), and moderately and positively with performance in the Flanker task ($r = .399$, $p=.041$).

As was the case in experiments 2 and 3, children were asked a comprehension question after each sentence in the experiment (questions were the same as experiment 3, see Appendix A). The aim was to gain insight into the strategy the children were adopting in the word monitoring task. Comprehension scores were poor across the board (as compared to the typically-developing data), with similar rates between the two speed conditions: The mean number of questions answered correctly (out of 48) in the baseline condition was 36.94 (sd=5.48) and in the slow-rate condition was 38.11 (sd=4.93). A paired-samples t-test revealed that this difference was non-significant ($t(16)=-.88$, $p>.05$).

Although comprehension performance was worse in the SLI sample as compared to the typically-developing samples of this thesis, there is still evidence that the children were processing the whole sentence. Even in the baseline condition (which would have been the hardest for the children with SLI), comprehension accuracy rates were at almost 80%. If children were simply listening out for the target word, their comprehension performance would be much lower than this.

7.6. Summary

Taking all of the data into account, it appears that performance in the word monitoring task is reliably associated with attention and speed of processing, but not with variation in general linguistic ability. This is evidenced by consistent correlations across all experiments in this thesis between word monitoring task performance and the Walk-Don't Walk, Symbol Search and Flanker tasks. Further support for this notion comes from the finding that there were no significant correlations between word monitoring task performance and a wide variety of standardised measures of language and grammar.

The comprehension question data revealed that children were indeed processing the sentence's semantics, rather than simply listening out for the target word. In addition, the test-retest reliability was reassuringly high.

Collectively, the data discussed in this section suggest that the word monitoring task is reliable, and that individual differences in performance may be influenced by domain-general factors such as attention and speed of processing. Clearly children process the linguistic content of the sentences, since they are able to answer the comprehension questions, but on-line sensitivity to grammaticality per se does not appear to be related to variation in underlying general language ability.

Chapter 8. General Discussion

8.1. Research background, rationale and aims of the thesis.

Whilst most children acquire the vocabulary and grammatical rules of their native language with relative ease, some children experience difficulty. Children with SLI demonstrate impaired acquisition of language and grammar, despite otherwise normal development. A particular area of difficulty for children with SLI is that of inflectional morphology, with verb inflections being the most problematic for these children to master, and noun inflections being relatively unaffected by the disorder (Leonard, 2014). Theories that attempt to explain the aetiology of SLI can usually be classified as either ‘domain specific’ or ‘domain general’. Theories that are domain specific argue that there is a particular linguistic function that is impaired in SLI, which causes the difficulties with language and grammar that these children experience (e.g. Rice & Wexler, 1996). Domain general approaches on the other hand suggest that deficits in wider cognitive areas negatively impact upon the acquisition of language and grammar in children with SLI.

There has been some promising research that has indicated that the difficulties experienced by children with SLI may indeed be the result of a wider cognitive deficit, rather than a specific linguistic one. Specifically, literature has suggested three possible cognitive impairments that may play a role in the aetiology of SLI: speed of processing (e.g. Miller et al., 2001), phonological working memory (e.g. Gathercole & Baddeley,1990) and auditory (speech-in-noise) processing (e.g. Ziegler, 2005; 2011).

Although the three cognitive theories outlined above have some strong supporting evidence indicating a link between cognitive and linguistic impairments, there is a significant lack of literature in the field that ties these accounts to the *inflectional* difficulties seen in SLI. Given that deficits in inflectional morphology are a hallmark of SLI, it is important for any theory to encompass this, too. In view of this, this thesis set out to investigate whether the Speed of Information Processing, the Phonological Working Memory and/or the Auditory Processing accounts of SLI can adequately explain the inflectional morphology deficits that are so persistent in the disorder. Throughout the thesis, there has been particular focus on the Surface Hypothesis of Leonard and colleagues (see Leonard, 2014 for a review), which is a hybrid account of SLI that merges linguistic and cognitive (speed of processing) accounts.

8.2. Summary of the Experiments.

This thesis consisted of four interrelated experiments. The first three experiments of this thesis set out to simulate an SLI-like pattern of inflectional difficulty in typically-developing children by increasing cognitive load (various stressors) during sentence processing. The premise was that if typically-developing children demonstrated an SLI-like pattern of inflectional difficulty (that is, verb inflections became impaired whilst noun inflections remained robust) when cognitive stress was introduced during sentence processing, support would be gained for the domain-general theories of the disorder. The last experiment looked to reduce cognitive load in children with SLI, in an attempt to alleviate some of their inflectional difficulties and effectively 'reverse' the cognitive load paradigm. Inflectional awareness was assessed using an on-line word monitoring task in all four experiments.

The first experiment of this thesis tested the speed of processing account of SLI by speeding sentences. Typically-developing children were asked to complete a word monitoring task when sentences were presented at normal, 10% speed compressed, 20% speed compressed or 30% speed compressed rates. It was found that children demonstrated sensitivity to all inflections under investigation when sentences were presented at normal and 10% faster-than-normal levels. However, when sentences were speeded by 20%, sensitivity to the regular past tense *-ed* inflection became impaired. When sentences were speeded by 30%, sensitivity to the third person *-s* inflection also became impaired. The control inflection, the progressive *-ing*, remained robust in the face of the cognitive stress (the noun items were confounded by ceiling effects). The finding that stressing speed of processing can result in an SLI-like pattern of inflectional difficulty provided support for the notion that SLI may be the consequence of a more general cognitive deficit, rather than a specific linguistic one.

Although the findings of experiment 1 were promising, they were somewhat limited in that the only cognitive stressor was speed. As such, it was unclear whether speed was the key stressor, or whether *any* cognitive stressor would result in an SLI-like pattern of inflectional impairment in the typically-developing participants. In view of this, experiment 2 of this thesis compared the effects of several cognitive stressors: speed (30% compression) to test the speed of information processing account, long sentences to test the phonological working memory account of SLI, and noise-masked sentences (multi-talker babble and signal-correlated noise) to test the auditory processing account. In addition, the inflections studied in this experiment (third person -*s* and regular plural -*s*) were controlled with regards to phonological saliency, in an attempt to test the Surface Hypothesis of SLI. The results showed that only the speed stressor resulted in an SLI-like pattern of inflectional impairment in the typically-developing participants; that is, sensitivity to the third person -*s* became impaired when sentences were speeded by 30%, but sensitivity to the plural -*s* remained intact. This was not the case when sentences were lengthened or noise-masked (grammatical sensitivity remained unimpaired across the board), suggesting that there is something 'special' about speed of processing in SLI. However, the discussion of this experiment included two caveats: 1) the noise may not have been noisy *enough* to stress the cognition of the children to a level that would begin to impair their inflectional sensitivity and 2) the past tense inflection should be included, since difficulties with this inflection are a hallmark of the inflectional deficit seen in English-speaking children with SLI.

In order to address these two caveats, experiment 3 of this thesis calibrated the signal-to-noise ratio of the two noise masks from experiment 2, akin to what was done with the speed compression rates in experiment 1. Sentences were masked at either 0dB, -4dB or -8dB signal-to-noise ratio. Both multi-talker babble and signal-correlated noise masks were used, and the regular past tense -*ed* was added back in to the stimulus set (alongside the third person singular -*s* and the regular plural -*s* as per experiment 2). It was found that, although decreasing the signal-to-noise ratio did decrease *overall* grammatical sensitivity, it did not result in a *specific* impairment, like we see in SLI. That is, sensitivity to *all three* inflections was reduced when the noise mask intensity increased, rather than demonstrating a verb-noun discrepancy as is seen when sentences are speeded.

The findings from the first three experiments of this thesis indicate that there may well be something ‘special’ about speed as a factor in the aetiology of SLI, rather than nonspecific cognitive deficits. In order to test this hypothesis fully, the last experiment of this thesis (experiment 4) looked to ‘reverse the paradigm’ by slowing sentence presentation rate down for children with SLI. If an impaired speed of processing *is* central to the inflectional impairments seen in SLI, and *if* this sits somewhere around the 30% mark, one would expect that slowing sentences by 30% might improve the inflectional impairments seen in SLI. However, the introduction to experiment 4 highlighted a very important point to consider before this paradigm can be ‘flipped’: there is no evidence in the literature to suggest that children with SLI demonstrate their classic hierarchy of inflectional difficulty in on-line (word monitoring task) measures. Accordingly, this needed to be assessed first. Interestingly, it was found that children with SLI **did not** demonstrate their classic pattern of inflectional difficulty when grammatical awareness was measured via an on-line word monitoring task. In fact, children showed grammatical impairment in all inflections under investigation: The regular past tense -*ed*, the third person singular -*s* and the regular plural -*s*. This is at odds with what we know about the naturalistic and off-line language skills of children with SLI, where the plural -*s* appears to be relatively unaffected. However, when sentences were slowed by 30%, the children with SLI demonstrated significant sensitivity to the third person -*s* and the regular plural -*s* inflections; they remained impaired in the regular past tense -*ed* inflection in this slow-rate condition.

8.3. Theoretical Implications: SLI as a Limitation in General Processing Capacity.

The literature reviewed in chapter 1 showed that whilst SLI is primarily a linguistic deficit, it may not be as specific as once thought. There is a substantial body of evidence to suggest that children with SLI demonstrate deficits in non-linguistic domains, as well as linguistic ones. As Leonard (2014) notes, these non-linguistic deficits are not usually severe; if they were, it is unlikely that these children would meet the classic diagnostic criteria for SLI in the first instance. Leonard (2014) goes on to argue that the evidence demonstrating subtle non-linguistic difficulties in children with SLI is so widespread that any theory of SLI needs to encompass this, too. What separates theories is whether they regard these non-linguistic weaknesses as central to the disorder, or simply a by-product of a more fundamental linguistic deficit.

In an interesting viewpoint, Leonard (2000) highlights that "any proposal of limited processing capacity carries the assumption that within some domain, the specific nature of the material is less important than how this material is mentally manipulated" (p. 237). Leonard (2000) suggests those theories of SLI that argue for a cognitive deficit being central in the disorder use the concepts of space, energy and/or time (cognitively-speaking) to explain the language profile of children with SLI (e.g. Kail & Salthouse, 1994; Salthouse, 1985). For instance, the Phonological Working Memory deficit account of SLI speaks to the notion of space: that is, there is not enough phonological workspace to effectively process language. Auditory processing accounts relate to the concept of energy: children with SLI do not have the required 'fuel' to complete a linguistic task, such as listening to speech in noise. Finally, theories that suggest SLI is the result of a deficit in speed of information processing tie into the 'time' concept: Children struggle to complete all of the language-processing steps in a time-effective manner, leading to incomplete linguistic representations. It is important to note that the three processing notions of space, energy and time are not mutually-exclusive, and that tasks can draw on more than one.

Whilst it is not in doubt in the literature that children with SLI demonstrate wider, non-linguistic deficits, it is in contention whether the non-linguistic deficits are primary or secondary to the language difficulties seen in the disorder. The findings of this thesis suggest the former: children who ordinarily have complete and robust linguistic representations demonstrated very specific grammatical impairments when cognitive load (speed of processing) was stressed. This suggests that language skill is contingent upon cognitive ability, and not the other way around.

Supporting this notion is a small body of evidence showing that cognitive limitations are sometimes even more important than language factors when determining the performance of children with SLI on a variety of linguistic and non-linguistic tasks. For instance, Tallal (1975) studied the ability of children with SLI to manipulate objects of various shapes/sizes/colours in response to verbal instructions that were either cognitively-complex or grammatically-complex. Tallal found that children with SLI found the cognitively-complex instructions more difficult than the grammatically-complex instructions. For example, the children with SLI struggled more with the cognitively-complex instructional sentence *"point to the blue circle, the green square and then the yellow triangle"* than the grammatically-complex sentence *"before touching the yellow circle, pick up the red square"*. Tallal argued that her findings demonstrated that it was the number of attribute combinations that determined their level of difficulty for the children, as opposed to the grammatical complexity of the instructional sentence, and therefore children with SLI struggled more on a task the stressed cognition, rather than grammatical complexity.

The findings of Johnston and Smith (1989) extend the idea that cognitive deficits can be more severe than language deficits in children with SLI. They designed an experiment whereby children with SLI and age-matched controls played a game of 'follow the leader' with adults. The game had two parts: linguistic and non-linguistic. In the linguistic part, children were given instructions that detailed which objects to select from an array, such as "pick two houses that are the same size" or "pick two objects that are the same colour". The children with SLI performed just as well as the age-matched group in this part of the experiment. In the non-linguistic task, children saw the adults select objects from an array, and they were required to mirror the rules of the selections using their own array. For example, adult one would have an array of houses which included a small red house, a medium yellow house and a large yellow house. Adult two would have an array that had a medium blue house, a large red house and a small red house. Adult one would select the two yellow houses and adult two would select the two red houses. The 'rules' of this particular round were therefore to select two items of the same colour, irrespective of size. The child would be given an array that was different to both adults', but that allowed them to 'follow the leader' (e.g. for the current example, the child's array might include a small green house, a medium pink house and a large green house: they would need to pick the two green houses to pass the round). In this non-linguistic part of the experiment, the children with SLI performed very poorly, as compared to the age-matched group, who in turn performed very well on this task (as well as the linguistic task). Johnston and Smith (1989) concluded that their experiment demonstrated that processing deficits can outweigh linguistic deficits in SLI, and that the non-linguistic task in their experiment required the greatest processing capacity as children had to infer the 'rule' (whereas the children were told the 'rule' in the linguistic task).

The work of Tallal (1975) and Johnston and Smith (1989) suggest that cognitive deficits may well be central to SLI, and in some instances can even outweigh the linguistic deficits. This idea is further supported by O'Hara and Johnston (1997), Riddle (1992) and Bishop and Adams (1992), who all demonstrated cognitive impairments more severe than linguistic counterparts in children with SLI (see Leonard, 2014 for a review). This strengthens the broad argument of this thesis: that a domain-general deficit is central to the aetiology of SLI. The question now speaks to what particular domain is the most impaired in SLI. The findings of the collection of experiments within this thesis strongly suggest that the deficit lies within speed of information processing.

8.3.1. Speed of Processing in SLI. Collectively, the four experiments of this thesis suggest that the inflectional impairments in SLI may indeed be the result of an impairment in speed of processing. The findings from experiment 4 showed that children with SLI were slower than the age-matched controls to response to basic auditory tones (in the basic reaction time task), visual information (the Flanker task) and linguistic information (in the word monitoring task). This supports the Generalised Slowing Hypothesis that was discussed in section 1.3.5.2.1, and adds to the bank of literature showing children with SLI are slower than typically-developing peers on a vast range of linguistic and non-linguistic tasks, including (but not limited to) mental rotation (Johnston & Ellis Weismer, 1983), picture naming (e.g. Anderson, 1965), word monitoring (e.g. Montgomery & Leonard, 2006), peg-moving (Bishop, 1990) and grammaticality judgements (Wulfeck and Bates, 1995).

In the Generalised Slowing Hypothesis, Kail (1994) proposed that in order to perform any given task, one must complete several processes. For example, in a simple picture naming task, a participant must i) recognise the picture ii) retrieve the correct name iii) formulate the word and iv) pronounce the word. As such, the speed which a typically-developing child can complete a picture naming task will be influenced by the time required to complete each process, as shown in (1)

(1) $RT_{\text{(typically developing)}} = a + b + c + \ldots.$

where *a* is the time needed to complete the first step in the task, *b* is the time needed for the second process, and so on. According to Kail (1994), children with SLI are slower than typically-developing children to complete each process by a constant factor, as represented in (2)

(2) $RT_{\text{(SLI)}} = m(a + b + c + \ldots.)$

where *m* is the degree of 'slowing' experienced by children with SLI (e.g. -30%) (see Leonard, 2014 for a complete review of Kail's work).

In a meta-analysis of 5 experiments spanning 22 various reaction time tasks, Kail (1994) reported that children with SLI experience a 'slowing' of approximately 33%, as compared to age-matched controls, regardless of task type. That is, Kail found that children with SLI were around 33% slower than their peers to complete the tasks assigned, irrespective of whether they were linguistic or non-linguistic. This was further supported by Miller et al. (2001), who reported an approximate slowing rate of 14% in their experimental SLI data. The findings from the experiments within this thesis further concur. Experiment 1 carefully calibrated the speed of sentence presentation rate, and found that the most accurate speed at which to simulate inflectional deficits in SLI was 30%. Reassuringly, this was replicated in experiment 2 of this thesis, suggesting that SLI may be associated with a 'generalised slowing' of approximately 30%.

The suggestion that children with SLI experience a slowness to process information by approximately 30% is especially supported by experiment 4 of this thesis. In this experiment, children completed three speeded measures: the basic reaction time task, the Flanker task and the word monitoring task. Table 30 below shows the mean raw reaction times for each of these tasks for the two groups, as well as the percentage difference (to demonstrate the percentage of slowing). It can be seen from the table that the speed at which the children with SLI performed the basic auditory RT task and the Flanker task were similar to the 33% suggested by Kail (1994).

Task	Group	Mean RT (ms)	% change
Basic auditory RT	TD	371	29.14
	SLI	479	
Flanker Task	TD	425	38.62
	SLI	590	
Word Monitoring Task (baseline)	TD	624	134.75
	SLI	1464	

Table 30. Mean reaction times for the three speeded tasks for the SLI and age-matched group. The percentage change represents the degree of slowing experienced by the SLI group (experiment 4).

The children with SLI completed the word monitoring task at a substantially slower speed than the typically-developing controls. This could be in part due to the extreme complexity of the word monitoring task. To perform this task, a child had to hold the target word in memory, inhibit response to all non-target stimuli and respond to the target with speed. In addition to this, the child needed to listen to the sentence content in order to correctly answer the comprehension question at the end. Children with SLI have been shown to have difficulties with working memory (e.g. Gathercole & Baddlely, 1990), and this particular task places demands on memory not only for holding the target word, but also for answering the comprehension question. In view of this, it is somewhat unsurprising that the children performed so much slower than their typically-developing counterparts.

Further supporting the notion that children with SLI experience a slowing of approximately 30% comes from the slowed condition in experiment 4. Children with SLI were impaired on grammatical sensitivity across the board when sentences were presented at a normal rate in this experiment, but when sentences were slowed by 30%, the children with SLI became much more sensitive to the third person singular and plural morphemes. This finding is comparable to other research in the field. For example, Montgomery and Leonard (2006) found that the word monitoring task performance of children with SLI was comparable to controls when sentences were presented 25% slower. In addition, Ellis Weismer and Hesketh (1996) found that the nonword learning of children with SLI was comparable to age-matched controls when they were presented at a slower-than-normal rate. Both studies found deficits when the sentences were presented at a normal rate.

The findings of this thesis agree with the work of Kail (1994) who suggests a slowing rate of approximately 33% in children with SLI. Both Miller et al. (2001) and Windsor and Hwang (1999) reported generalised slowing in their SLI samples too, but they reported slowing rates of 14% and 18% respectively. It may be that these two studies reported less slowing than the current study and Kail (1994) because of age differences. In Windsor and Hwang's study, the children with SLI were, on average, 136 months old, which is substantially older than the average age of 102 months for the children with SLI in the fourth experiment of this thesis. The study by Miller et al. (2001) used children who were around 110 months. The studies included in Kail's meta analysis had participants that were on average 100months old, which is much closer in age to the 102 months of the children in experiment 4 of this thesis. As such, it seems possible that the degree of slowing experienced by children with SLI reduces with age. A longitudinal study tracking the performance of groups of SLI and typically-developing children on a variety of linguistic and non-linguistic tasks would help answer this.

8.3.2. Assessing The Surface Hypothesis. If we accept that the inflectional difficulties in children with SLI can be explained by generalised slowing, which results in impairments in the speed with which normal-rate language can be processed, we need to consider exactly how speed and inflectional morphology are related. In other words, why might a reduced speed of processing result in impaired morphological representations? Taken together, the findings of this thesis lend partial support to the Surface Hypothesis as an answer to this question, to the extent that they show a role for the phonetic salience of the inflection in determining performance. The Surface Hypothesis argues that in SLI, a child's reduced speed of processing interacts with the phonological properties of inflections to determine their affectedness. In experiments 2, 3 and 4, the third person singular -*s*and the regular plural -*s* were matched with regards to phonetic salience (amplitude and duration), and the stimuli were homophone pairs to eliminate articulatory confounds. If a strong version of the Surface Hypothesis is correct, and phonetic salience is the key factor determining processing of an inflection, then one would expect the two -*s* inflections to be impaired to the same degree when speed is manipulated, as they are phonetically matched.

The results of Experiment 2 showed that there was differential performance between the (matched) third person singular -*s* and the plural -*s* when sentences were speeded by 30% for the typically-developing children. That is, a strong version of the Surface Hypothesis was not supported, since phonetic salience alone cannot explain the pattern: the main factors that differentiate the two -*s* inflections are grammatical complexity and semantic salience (following Slobin's (1985) grammaticizability hierarchy): the 3rd person singular has features of both number and tense, whereas the plural concerns only number. Furthermore, the noun plural is much more semantically-salient than the 3rd personal singular verb inflection. An interestingly different pattern emerges from the SLI data in this thesis, which is more clearly supportive of the Surface Hypothesis. When children with SLI processed slower-than-normal sentences, they were able to detect grammaticality in the two -*s* inflections but not in the past tense -*ed* inflection. Acoustic analyses showed that the -*ed* was both quieter and shorter in duration than the two -*s* inflections, and it was therefore less phonologically salient. However, in terms of grammatical complexity and semantic salience – and indeed age of acquisition (Brown, 1973) – these two verb inflections are equivalent. This finding therefore lends strong support for the Surface Hypothesis: Speed of processing interacts with phonetic salience, such that when speed is manipulated, it is the morpheme's phonetic salience that determines affectedness.

In addition to the carefully controlled phonetic salience in the experimental setting described here, it is also important to consider how children experience these morphemes in 'real life'. Although the saliency of the two *-s* inflections was matched in experiments 2, 3 and 4 of this thesis, they are not matched in 'real life'. In everyday language, the third person *-s* is significantly quieter and shorter than the plural *-s* (see Black & Chiat, 2003). As such, children have had a lifetime of hearing the verb *-s* as less phonologically salient than the noun *-s*, which may impact upon the robustness of their morphological representations. It is possible that this explains why the typically-developing children in experiments 2 and 3 showed differential performance between the two *-s* inflections in the stressed conditions, despite the 'matching': Their representations have differing levels of strength as a result of the language they hear having unmatched verb and noun *-s* inflections.

The baseline data for the typically-developing children in experiments 1, 2 and 3 are consistent with the patterns that emerged in the speeded conditions. Although these children had age-appropriate language, and were highly sensitive to the grammaticality within all inflections studied, they showed a hierarchy of reaction time speed, such that the most 'difficult' inflection, the past tense *-ed*, was associated with the slowest reaction times and the 'easiest' inflection, the plural *-s*, was associated with the fastest reaction times. Reaction times to the third person singular *-s* inflection always sat somewhere between these two inflections. This gradient of reaction times for normal-rate inflections in typically-developing children is also seen repeatedly in the word monitoring literature (e.g. Montgomery & Leonard, 1998; 2006). Collectively, these findings suggest that even in children with typical language skills, there is some inherent hierarchy of difficulty within inflectional morphology, and that both grammatical complexity and phonetic salience play a role in the strength of inflectional representations. Interestingly, this hierarchy partially –

but not perfectly - mirrors the typical order of morphological acquisition in English-speaking children, further strengthening the argument that those inflections that are easiest to acquire have stronger representations, as they are acquired earlier and therefore experienced more.

Although the Surface Hypothesis seems like a plausible explanation for the relationship between a speed of processing deficit and inflectional impairment in SLI, there are some shortcomings in the theory that need to be considered. For instance, children with SLI have difficulty using the accusative-case pronouns in subject position (e.g. *me take that; them see the tuba*) (Loeb & Leonard, 1991), despite their extremely high phonological saliency (Leonard, 2014). If it was solely the acoustic properties of items that determined their affectedness in SLI, accusative-case pronouns in the subject position would *not* be impaired. In addition, there is cross-linguistic data from non-English SLI samples that further questions the validity of the Surface Hypothesis. For example, in Swedish, both the present tense and past tense inflections are always phrase-final, and as such are highly salient (Leonard, 2014). According to the predictions of the Surface Hypothesis, these two inflections would not be impaired in SLI. However, Hansson, Nettelbladt and Leonard (2000) found that Swedish-speaking children with SLI performed worse than language-matched children on the past tense inflection. This was not the case with the present tense inflection, which appeared to be unimpaired, relative to children with comparable language skills. A similar high-saliency-impairment was shown in Cantonese-speaking children with SLI (Fletcher, Leonard, Stokes & Wong, 2005). Collectively, this data somewhat weakens the Surface Hypothesis as a full and complete explanation of the grammatical difficulties experienced by children with SLI. As Leonard (2014) so aptly summarised:

> *"… it seems that the difficulty processing morphemes of brief duration probably contributes to the serious deficits in grammatical morphology seen in children with SLI, but it is not likely to be the principal force behind these deficits"* (p. 294)

In addition, the Surface Hypothesis strongly argues that it is phonological saliency that interacts with speed of processing to determined affectedness. According to Leonard (2000), the term ‘phonological saliency’ relates to both amplitude *and* duration. In some respects, it is unsurprising that manipulating speed of processing is the most likely to affect sensitivity to the regular past tense *-ed*, given that this is one of the weakest morphemes: it is both quieter and shorter than, for example, the third person *-s* and plural *-s*. From this, it is unclear where amplitude fits in. It seems likely that something that is shorter in duration is more susceptible to manipulations in speed of processing, because if a child is struggling to ‘keep up’ with the sentence they are more likely to ‘miss’ the fastest morphemes. However, if amplitude also played a role, one would expect a noise mask to have a similar effect. Just as speed affects morphemes that are fast, noise should affect morphemes that are quiet. But this was not the case. Noise did not affect the regular past tense – the quietest morpheme – in experiment 3. Perhaps then, only speed is important to determine affectedness of a particular morpheme, and amplitude has little bearing? In order to test this, we would need morphemes that could disentangle speed and amplitude; a design that includes ‘fast + quiet’, ‘slow + quiet’, ‘fast + loud’ and ‘slow + loud’ morphemes would allow the assessment of the independent effects of speed and amplitude.

8.3.3. The difference between verb and noun morphology. Throughout this thesis, a hierarchy of inflectional difficulty has been shown in both the typically-developing and specifically-language-impaired samples. That is, noun morphology appears to be ‘easier’ and less susceptible to damage, and verb morphology appears to be ‘harder’ and more vulnerable in the face of cognitive stress. Even in optimum listening conditions, children who have age-appropriate linguistic and morphological representations demonstrate slower reaction times to targets following verbs than they do nouns (see experiments 1, 2 and 3). As such, when cognitive stress is introduced (particularly speed), this hierarchy of difficulty begins to determine each morpheme’s vulnerability to damage.

What is important to note is that this hierarchy of difficulty is largely reflective of the typical order of morphological acquisition, as demonstrated by

Brown (1973) and de Villiers and de Villiers (1973), and confirms the arguments in the literature regarding grammatical complexity (e.g. Chiat, 2000), as well as that of phonological saliency. That is, those morphemes that have a clear grammatical function, whose form-function mappings are well-specified, and whose phonological saliency is strong are acquired earlier and are less susceptible to damage (e.g. the plural -*s*), and those morphemes (e.g. the past tense -*ed*) that are more complex in nature and less phonologically-salient are acquired later and are the first to become damaged when speed of processing is compromised.

The finding from experiment 4 that showed children with SLI do not demonstrate the classic hierarchy of difficulty in the baseline word monitoring condition was surprising, and suggests that the inflectional deficit is even more pronounced and widespread than first thought. Rather than showing a gradient of difficulty, children with SLI showed impairments in all three inflections under investigation when sentences were presented at a normal rate, including the noun plural -*s* which is usually relatively unimpaired in the disorder (see Leonard, 2014 for a review). However, all of the research studies that show it to be unimpaired use naturalistic or off-line measures, both of which allow children time to think more explicitly about their language. When children are not given time to think explicitly, as per the word monitoring task, they appear to show difficulties with *all* inflections, not just verb ones. It is therefore possible that children with SLI do have difficulties with most inflections, including noun morphology, but when they are given more time (e.g. in off-line tasks or when sentences are slowed down) they are able to resolve these difficulties with the 'easier' items.

Following on from this, the findings of experiment 4 show that even when cognitive load is lightened (by means of slowing down sentence presentation rate) children with SLI remain impaired in the regular past tense inflection. The discussion section of experiment 4 (section 6.4) suggested that this highlights just how hard this morpheme is for children to master, potentially because it is both grammatically complex and phonetically non-salient. A simple, short-term 'lightening of the load' as per experiment 4 may not have been enough to improve the performance of children with SLI on this particular inflection. It was suggested that a longer-term intervention programme is needed if deficits in the past tense are to be alleviated, which works with children with SLI on enhancing speed of processing skills and the processing of perceptually-weak items.

8.3.4. Reassessing the Phonological Working Memory and Auditory Processing Deficit accounts of SLI. The findings of the experiments contained within this thesis strongly support the notion that the inflectional difficulties experienced by children with SLI may be the result of a speed of processing deficit. Experiment 2 investigated whether stressing phonological working memory or auditory processing (speech in noise) could result in an SLI-like profile of inflectional impairment; results were nonsignificant for both stressors. Experiment 3 looked to test the Auditory Processing hypothesis in more detail by carefully calibrating the signal-to-noise ratio of the noise masks, but again failed to induce an SLI-like profile of impairment. In view of these nonsignificant results, it can be argued that this thesis did not find any support for the idea that a deficit in either of these two domains is central to the aetiology of SLI.

This lack of support for either hypothesis was surprising, and somewhat unexpected given previous literature. With regards to the phonological working memory account, it is widely accepted in the literature that children with SLI demonstrate difficulties in this domain, and that they are a hallmark of the disorder (e.g. Bishop, 1997). In addition, both Hayiou-Thomas et al., (2004) and Witherstone (2010) were able to simulate the SLI inflectional profile in typically-developing children by lengthening sentences (by way of increasing the number of words per sentence, just as experiment 2 did).

There are a few possible reasons for why experiment 2 failed to support the literature. Firstly, the studies of Hayiou-Thomas et al., (2004) and Witherstone (2010) measured inflectional awareness via an off-line grammaticality judgement task. In this task, children must maintain the sentence in their working memory store in order to answer a question regarding its grammaticality at the end. By its very nature then, the grammaticality judgement task places a much heavier demand on the memory system than the word monitoring task does. With this in mind, it is somewhat foreseeable that lengthening sentences would impair grammatical sensitivity for this task.

This argument introduces the idea that the nature of the task needs to be considered in a paradigm such as simulation. Perhaps lengthening sentences did not affect word monitoring task performance because the task does not require processing of the whole sentence in order to do well? Children only need to listen out for the target word; and so no amount of increased words would affect performance … *if this was their strategy.* However, experiments 2, 3 and 4 of this thesis explicitly told children to listen to the sentence as they would be answering a question about the sentence content at the end, which effectively *gave* the children a strategy. Children would therefore need to retain the words contained within the sentence in order to answer the comprehension question (the very high performance across all experiments on the comprehension questions supports the notion that children were indeed maintaining the whole sentence until the end). So, although the word monitoring task may not ordinarily rely on working memory, the addition of the comprehension questions in this thesis added this component.

Secondly, it may be the case that lengthening sentences was not the appropriate stressor to use in order to test the Phonological Working Memory hypothesis of SLI. By definition, the Phonological Working Memory system relates to how much *work* one is required to carry out on phonological information. Lengthening sentences did not increase the amount of *work*, it simply 'filled up the store' more. That is, lengthening sentences may have increased load, but not complexity. In order to truly stress phonological working memory, some form of divided or dual attention task would need to be introduced during sentence processing (see section 4.4 for a more complete discussion on this). However, it is felt that this would increase the task complexity far beyond the capabilities of the young children that are of interest here.

Finally, it may be the case that whilst many children with SLI do have phonological working memory deficits, they are just not central to the disorder. In other words, children with SLI may have co-occurring phonological working memory deficits, but these do not determine the severity of morphological impairment. It may also be that phonological working memory is problematic in only a subset of children with SLI (e.g.. Alt, 2012; Larkin & Snowling, 2008).

There are several possible explanations for why this thesis failed to find an effect of lengthening sentences upon inflectional sensitivity. However, the potential reason(s) for why there was no specific effect of noise mask is less clear. The simplest and most plausible explanation is that perhiperal auditory processing simply is not a factor that can account for the inflectional morphology deficits in SLI. Of course, it may be a contributory factor to the overall language and grammatical weaknesses in the disorder, but this thesis does not support the notion that the specific pattern of inflectional difficulty in SLI can be explained by difficulty with extracting speech-in-noise. Indeed, whist research (e.g. Ziegler, 2005; 2011) has found children with SLI to struggle with extracting speech-in-noise, the link between speech-in-noise deficits and *inflectional morphology* has not been demonstrated in the literature.

8.4. Limitations and Future Directions

There are limitations within the experiments of this thesis that must be acknowledged, and that open avenues for future research. Firstly, whilst the findings strongly suggest that a speed of processing deficit may be central to the inflectional difficulties experienced by children with SLI, it must be remembered that only one task type and a limited number of inflections were used, and so the conclusions made are only within the confines of this thesis' methodological choices. The regular past tense *-ed,* the third person singular *-s* and the regular plural *-s* dominated this thesis. However, children with SLI have varying degrees of difficulty with many aspects of grammatical processing: For example, research consistently shows impairments in inversion in wh- questions (e.g. Rowland & Pine, 2003), as well as auxiliary and copula forms (see Lieven, 2008 and Ambridge & Lieven, 2011) In addition, there are deficits outside of grammar, such as sentence comprehension and vocabulary knowledge, and in different modalities and tasks, such as production and grammaticality judgement (see Leonard, 2014 for a comprehensive review). Any explanation of SLI needs to be able to measure, demonstrate and explain deficits in all of these domains if it is to comprehensively describe the aetiology of the disorder. As such, the findings of this thesis need to be challenged with other areas of weakness in SLI, and using different measurement tools.

Secondly, although this thesis was designed to examine the nature of the inflectional difficulties in SLI, the only experiment that included children with SLI was the last one – experiment 4. The first three experiments used a simulation paradigm with typically-developing children. Whilst this paradigm certainly has strong experimental merit (see sections 1.2 and chapter 2), it is no substitute for confirming hypotheses in the actual population (i.e. children with SLI). More work is needed that looks directly at children with SLI, and that attempts to alleviate their difficulties by 'reversing the paradigm' (reducing cognitive load). In addition, the conclusions drawn from experiment 4 must be taken with extreme caution, as there was a lack of appropriate control groups. A replication of experiment 4 would be sensible, using SLI, age, and language-matched groups, in order to make more firm conclusions as to the nature of impairment in SLI relative to their age and linguistic ability.

Finally, a more detailed analysis of individual differences within SLI samples would be useful, and may yield some interesting results. SLI is an extremely heterogeneous group (Bishop, 1997), and there is an enormous amount of variability within any given SLI sample. It is therefore unlikely that a single explanation regarding the cause of inflectional difficulties in the disorder will fully encompass every member of the group. Indeed, whilst this thesis seems to indicate that speed of processing plays a central role in the grammatical deficits in SLI, this does not explain why there are a significant proportion of children with SLI who do not show any reduced processing speed (see. Miller et al., 2001). In addition, although this thesis provides some suggestion that the inflectional difficulties in SLI are mediated by speed of processing, the influence of phonological working memory and auditory perception cannot be discounted. There is a bank of strong evidence suggesting that both of these domains are impaired in SLI (e.g. Conti-Ramsden, 2003; Gathercole & Baddley, 1990; Zeiger, 2005; Ziegler, 2011), and it may be the case that these deficits are present but less severe than speed of processing. Following on from this, it might be the case that the cognitive impairments have an additive effect on inflectional processing, such that a child with impairments in just speed of processing has stronger morphological capabilities than a child that shows deficits in speed of processing *and* auditory processing (for example).

8.5. Conclusion

To conclude, this thesis set out to examine whether a general cognitive deficit can help explain the specific profile of inflectional difficulty seen in Specific Language Impairment. The fact that children with SLI show a specific hierarchy of inflectional impairment (rather than a global grammatical deficit) suggests that it is not the underlying grammar that is directly responsible for the disorder. Through a series of experiments, support was gained for the notion that children with SLI experience generalised slowing, and that this may result in impaired inflectional morphology capabilities. The reduced speed of processing in children with SLI may interact with the phonological properties of inflections (cf. the Surface Hypothesis), such that morphological items that are relatively short in duration may be more vulnerable to impairment when children struggle to process real-time language in a time-effective manner. This thesis did not find support for deficits in phonological working memory or auditory processing as explanatory factors of the inflectional difficulties children with SLI experience, although that is not to say that they do not exist. The findings of this thesis require replication and expansion using both typically-developing and specifically-language impaired children, before firm conclusions can be drawn.

Appendices

Appendix A: All stimuli items across the four experiments

Appendix B: Coding script for PRAAT to generate signal-correlated noise

Appendix A: Stimuli for experiment 1, set A

SET A	Stem				Sentence (grammatical form)				Target			
	Stem	**Freq**	**Neighbours**	**Phonemes**	**Utterance**	**Word count**	**Target position**	**Syllable count**	**Target**	**Freq**	**Neighbours**	**Phonemes**
Past tense	Bake	11	19	3	Yesterday little smiling Jack baked cakes with his mum	9	6	13	Cakes	149	12	4
	Clap	32	6	4	Last week the whole school clapped happily after the play	10	7	12	Happily	89	0	6
	Hug	49	16	3	Last week Hannah hugged friends in the playground	8	5	10	Friends	492	3	6
	Watch	300	7	3	Yesterday the girls watched cartoons after school	7	5	11	Cartoons	5	1	6
	Drop	76	3	4	Yesterday the silly boy dropped food on the floor	9	6	12	Food	925	13	3
	Climb	173	3	4	Last week the man climbed mountains with his friend	9	6	10	Mountains	211	1	7
	Move	200	4	3	Yesterday helpful strong Liz moved boxes with her mum	9	6	13	Boxes	135	3	6
	Call	254	20	3	Yesterday Kate's mum called Grandad at home	7	5	10	Grandad	489	0	7
	Cook	300	11	3	Last week Jane's helpful mum cooked dinner for the children	10	7	13	Dinner	170	6	5
	Play	1095	6	3	Last week the happy boys played games after dinner	9	7	12	Games	108	4	4
		249	**9.5**	**3.3**		**8.7**	**6**	**11.6**		**277.3**	**4.3**	**5.4**
Third person	Kick	19	17	3	Every week the happy boy kicks footballs in the park	10	7	13	Footballs	3	0	7
	Chase	35	10	3	Every day the black dog chases cats in the garden	10	7	13	Cats	157	13	4
	Crack	51	10	4	Every day mum cracks eggs into the bowl	8	5	10	Eggs	462	0	3
	Bounce	70	2	4	Every week John bounces balls in the park	8	5	10	Balls	54	12	4
	Mix	78	12	4	Every week pretty Sarah mixes paint in art class	9	6	13	Paint	260	8	4
	Carry	130	3	4	Every day Tom's strong dad carries bags to the car	10	7	12	Bags	95	6	4
	Talk	211	14	3	Every week Hannah talks quietly at bed time	8	5	12	Quietly	78	0	7
	Walk	335	21	3	Every day the family walks quickly to the shops	9	6	12	Quickly	195	0	6
	Jump	327	6	4	Every day Alfie jumps high into the air	8	5	11	High	260	26	2
	Stop	892	8	4	Every week the car stops before the traffic lights	9	6	12	Before	598	0	5
		214.8	**10.3**	**3.6**		**8.9**	**5.9**	**11.8**		**216.2**	**6.5**	**4.6**

Appendix A: Stimuli for experiment 1, set A

Progressive	Fix	32	13	4	This week the clever Dad is fixing toys for his son	11	7	13	Toys	127	11	3
	Kiss	43	12	3	Today pretty little Alice is kissing grandma goodbye	8	7	15	Grandma	162	1	6
	Drip	30	5	4	Today the girl is dripping juice on the floor	9	6	11	Juice	35	4	3
	Sail	70	26	3	Today the grey captain is sailing boats on the sea	10	7	13	Boats	146	10	4
	Pick	114	19	3	Today John is picking flowers from the garden	8	5	12	Flowers	295	2	5
	Laugh	170	7	3	This week the children are laughing noisily at the cartoon	10	6	15	Noisily	3	0	6
	Start	222	8	4	This week the children are starting school at nine o'clock	10	7	13	School	1393	4	4
	Ask	300	0	3	Today James is asking questions in class	7	5	10	Questions	32	0	8
	Clean	276	2	4	Today the lady is cleaning tables after lunch	8	6	13	Tables	22	2	5
	Work	814	14	3	Today Billy is working late into the night	8	5	12	Late	187	20	3
		207.1	**10.6**	**3.4**		**8.9**	**6.1**	**12.7**		**240.2**	**5.4**	**4.7**
Plural	Cup	126	10	3	The dinnerlady put six cups neatly on the table	9	6	14	Neatly	8	0	5
	Pig	151	14	3	Sam saw nine pigs drinking water in the field	9	5	11	Drinking	41	0	7
	Song	124	11	3	Claire quickly played three songs loudly to her friends	9	6	11	Loudly	59	0	5
	Boy	844	13	2	The mum watched her two boys dancing to the music	10	7	12	Dancing	95	1	3
	Cat	1187	23	3	Jess saw five cats walking along the pavement	8	6	11	Walking	108	5	5
	Hand	295	8	4	The boy put two hands deep into his pockets	9	6	11	Deep	187	11	3
	Hat	514	24	3	The nice man put nine hats slowly into boxes	9	7	12	Slowly	203	1	5
	Bowl	54	18	3	Mum put four bowls gently on the table	8	5	10	Gently	59	0	6
	Duck	441	19	3	The boys saw two ducks swimming together on the water	10	7	14	Together	316	0	7
	Plate	62	8	4	Joshua put six plates under the table	7	5	10	Under	517	0	5
		379.8	**14.8**	**3.1**		**8.8**	**6**	**11.6**		**159.3**	**1.8**	**5.1**

Appendix A: Stimuli for experiment 1, set B

SET B	Stem				Sentence (grammatical form)				Target			
	Stem	Freq	Neighbours	Phonemes	Utterance	Word count	Target position	Syllable count	Target	Freq	Neighbours	Phonemes
Past tense	Kick	19	17	3	Last week the happy boy kicked footballs in the park	10	7	12	Footballs	3	0	7
	Chase	35	10	3	Yesterday the dog chased cats in the garden	8	5	11	Cats	157	13	4
	Crack	51	10	4	Yesterday Tom's mum cracked eggs into the bowl	8	5	10	Eggs	462	0	3
	Bounce	70	2	4	Last week smiling John bounced balls in the park	9	6	10	Balls	54	12	4
	Mix	78	12	4	Last week pretty Sarah mixed paint in art class	9	6	11	Paint	260	8	4
	Carry	130	3	4	Yesterday Tom's tall strong dad carried bags to the car	10	7	13	Bags	95	6	4
	Talk	211	14	3	Last week the two boys talked quietly at bed time	10	7	12	Quietly	78	0	7
	Walk	335	21	3	Yesterday the family walked quickly to the shops	8	5	13	Quickly	195	0	6
	Jump	327	6	4	Yesterday little Alfie jumped high into the air	8	5	13	High	260	26	2
	Stop	892	8	4	Last week the car stopped before the traffic lights	9	6	11	Before	598	0	5
		214.8	**10.3**	**3.6**		**8.9**	**5.9**	**11.6**		**216.2**	**6.5**	**4.6**
Third person	Fix	32	13	4	Every week the clever Dad fixes toys for his son	10	7	13	Toys	127	11	3
	Kiss	43	12	3	Every day pretty little Alice kisses grandma goodbye	8	7	15	Grandma	162	1	6
	Drip	30	5	4	Every day the girl drips juice on the floor	9	6	10	Juice	35	4	3
	Sail	70	26	3	Every day the captain sails boats on the sea	9	6	11	Boats	146	10	4
	Pick	114	19	3	Every week John picks flowers from the garden	8	5	11	Flowers	295	2	5
	Laugh	170	7	3	Every week the girl laughs noisily at the cartoon	9	6	13	Noisily	3	0	6
	Start	222	8	4	Every week the clever boy starts school at nine o'clock	10	6	13	School	1393	4	4
	Ask	300	0	3	Every day James asks questions in class	7	5	9	Questions	32	0	8
	Clean	276	2	4	Every day the happy lady cleans tables after lunch	9	7	14	Tables	22	2	5
	Work	814	14	3	Every week Billy works late into the night	8	5	11	Late	187	20	3
		207.1	**10.6**	**3.4**		**8.7**	**6**	**12**		**240.2**	**5.4**	**4.7**

Appendix A: Stimuli for experiment 1, set B

Progressive	Bake	11	19	3	Today Jack is baking cakes with his mum	8	5	10	Cakes	149	12	4
	Clap	32	6	4	This week the children are clapping happily after the play	10	7	15	Happily	89	0	6
	Hug	49	16	3	Today Hannah is hugging friends in the playground	8	5	11	Friends	492	3	6
	Watch	300	7	3	Today the girls are watching cartoons after school	8	6	12	Cartoons	5	1	6
	Drop	76	3	4	Today the silly boy is dropping food on the floor	10	7	13	Food	925	13	3
	Climb	173	3	4	This week the man is climbing mountains with his friend	10	7	12	Mountains	211	1	7
	Move	200	4	3	Today helpful strong Liz is moving boxes with her mum	10	7	14	Boxes	135	3	6
	Call	254	20	3	Today mum is calling Grandad at home	7	5	10	Grandad	489	0	7
	Cook	300	11	3	This week mum is cooking dinner for the children	9	6	12	Dinner	170	6	5
	Play	1095	6	3	Today the boys are playing games after dinner	8	6	12	Games	108	4	4
		249	**9.5**	**3.3**		**8.8**	**6.1**	**12.1**		**277.3**	**4.3**	**5.4**
Plural	Bell	162	12	3	The children heard the two bells ringing from the church	10	7	12	Ringing	19	2	5
	Toy	51	11	2	Hannah saw three toys lying on the floor	8	5	9	Lying	51	4	4
	Coat	176	20	3	Amy saw two coats hanging in the classroom	8	5	11	Hanging	62	4	5
	Tree	955	5	3	The man saw the seven trees moving in the wind	10	7	12	Moving	95	1	5
	Bag	392	16	3	Lucy's strong dad carried four bags carefully into the house	10	7	15	Carefully	141	0	5
	Boat	563	21	3	The sailor saw three boats floating on the water	9	6	12	Floating	30	1	6
	Chair	208	19	3	The teacher put six chairs behind the curtain	8	6	11	Behind	338	0	6
	Friend	219	2	5	The woman saw four friends running in the park	9	6	11	Running	265	4	5
	Ball	346	13	3	Fred kicked six balls hard into the football net	9	5	11	Hard	471	18	3
	Shoe	105	23	2	Milly took two shoes inside the house	7	5	9	Inside	522	0	5
		317.7	**14.2**	**3**		**8.8**	**5.9**	**11.3**		**199.4**	**3.4**	**4.9**

Appendix A: Stimuli for experiment 1, set C

SET C	Stem				Sentence (grammatical form)				Target			
	Stem	Freq	Neighbours	Phonemes	Utterance	Word count	Target position	Syllable count	Target	Freq	Neighbours	Phonemes
Past tense	Fix	32	13	4	Last week the clever Dad fixed toys for his son	10	7	11	Toys	127	11	3
	Kiss	43	12	3	Yesterday pretty little Alice kissed grandma goodbye	7	6	14	Grandma	162	1	6
	Drip	30	5	4	Yesterday the girl dripped juice on the floor	8	5	10	Juice	35	4	3
	Sail	70	26	3	Yesterday the old grey captain sailed boats on the sea	10	7	13	Boats	146	10	4
	Pick	114	19	3	Last week John picked flowers from the garden	8	5	10	Flowers	295	2	5
	Laugh	170	7	3	Last week all the children laughed noisily at the cartoon	10	7	14	Noisily	3	0	6
	Start	222	8	4	Last week the clever children started school at nine o'clock	10	7	14	School	1393	4	4
	Ask	300	0	3	Yesterday clever James asked questions in class	7	5	11	Questions	32	0	8
	Clean	276	2	4	Yesterday the happy lady cleaned tables after lunch	8	6	14	Tables	22	2	5
	Work	814	14	3	Last week tired Billy worked late into the night	9	6	11	Late	187	20	3
		207.1	**10.6**	**3.4**		**8.7**	**6.1**	**12.2**		**240.2**	**5.4**	**4.7**
Third person	Bake	11	19	3	Every day little smiling Jack bakes cakes with his mum	10	7	13	Cakes	149	12	12
	Clap	32	6	4	Every week the school claps after the play	8	5	10	Happily	89	0	0
	Hug	49	16	3	Every week Hannah hugs friends in the playground	8	5	11	Friends	492	3	3
	Watch	300	7	3	Every day the girl watches cartoons after school	8	6	12	Cartoons	5	1	1
	Drop	76	3	4	Every day the silly boy drops food on the floor	10	7	12	Food	925	13	13
	Climb	173	3	4	Every week the man climbs mountains with his friend	9	6	11	Mountains	211	1	1
	Move	200	4	3	Every day helpful strong Liz moves boxes with her mum	10	7	13	Boxes	135	3	3
	Call	254	20	3	Every day Kate's mum calls Grandad at home	8	6	10	Grandad	489	0	0
	Cook	300	11	3	Every week mum cooks dinner for the children	8	5	11	Dinner	170	6	6
	Play	1095	6	3	Every week the boy plays games after dinner	8	6	11	Games	108	4	4
		249	**9.5**	**3.3**		**8.7**	**6**	**11.4**		**277.3**	**4.3**	**4.3**

Appendix A: Stimuli for experiment 1, set C

Progressive	Kick	19	17	3	This week the boy is kicking footballs in the park	10	7	12	Footballs	3	0	0
	Chase	35	10	3	Today the dog is chasing cats in the garden	9	6	12	Cats	157	13	13
	Crack	51	10	4	Today mum is cracking eggs into the bowl	8	5	11	Eggs	462	0	0
	Bounce	70	2	4	Today John is bouncing balls in the park	8	5	10	Balls	54	12	12
	Mix	78	12	4	This week Sarah is mixing paint in art class	9	6	11	Paint	260	8	8
	Carry	130	3	4	Today Tom's tall dad is carrying bags to the car	10	7	13	Bags	95	6	6
	Talk	211	14	3	This week two boys are talking quietly at bed time	10	7	13	Quietly	78	0	0
	Walk	335	21	3	Today the family are walking quickly to the shops	9	6	13	Quickly	195	0	0
	Jump	327	6	4	Today Alfie is jumping high into the air	8	5	12	High	260	26	26
	Stop	892	8	4	This week cars are stopping before the traffic lights	9	6	12	Before	598	0	0
		214.8	**10.3**	**3.6**		**9**	**6**	**11.9**		**216.2**	**6.5**	**6.5**
Plural	Horse	441	10	3	The farmer saw six horses looking into the barn	9	6	13	Looking	487	4	5
	Girl	527	7	3	Sam saw three girls talking quietly together	7	5	12	Talking	73	4	5
	Plant	281	0	5	The girl had three plants growing in her garden	9	6	11	Growing	103	2	5
	Fish	784	8	3	The sailor saw eight fishes swimming in the sea	9	6	12	Swimming	154	4	6
	Book	541	14	3	The young boy had four books sitting on his shelf	10	7	11	Sitting	203	6	5
	Bird	287	18	3	The old man saw two birds flying in the sky	10	7	11	Flying	233	2	5
	Rat	122	24	3	Tom watched three rats making a nest in their cage	10	5	11	Making	297	4	5
	Kid	22	20	3	The dad watched two kids having fun on the computer	10	7	13	Having	235	2	5
	Cow	333	11	2	The friendly farmer saw seven cows eating grass	8	7	12	Eating	187	2	4
	Friend	219	2	5	Dad watched two friends playing in the garden	8	5	10	Playing	214	2	5
		355.7	**11.4**	**3.3**		**9**	**6.1**	**11.6**		**218.6**	**3.2**	**5**

Appendix A: Stimuli for experiment 2

Appendix A: Stimuli for experiment 2

Third person singular (verb)	Target	Freq of target	Target neigh	Target phonemes	Syllables before target	Sentence length (syllables)
The yellow car bumps along the road	*along*	427	0	4	5	7
The man coaches six football teams	*six*	200	17	4	4	8
The shop keeper dresses happy customers in new clothes	*happy*	419	4	4	6	14
The tall lady ducks under the door so she doesn't hit her head	*under*	517	0	5	5	16
The girl plants green vegetables in her garden	*green*	538	8	4	3	10
The postman stamps letters before putting them in the post box	*letters*	78	2	5	4	14
The king watches brave knights fighting to protect him	*brave*	211	6	4	4	12
The old man draws fish whilst sitting by the pond	*fish*	784	8	3	4	11
The naughty boy drops rubbish on the floor	*rubbish*	208	1	5	5	10
The teacher whistles loudly at the end of play time	*loudly*	59	0	5	5	13
The teacher leads happy children to the playground	*happy*	419	4	4	4	12
The strong builder hammers hooks into the wall	*hooks*	5	8	4	6	10
The teacher emails quiz questions to the children	*quiz*	8	1	4	5	12
The hungry girl pictures shops filled with sweets	*shops*	170	12	4	6	10
The clever teacher tests children in school	*children*	154	0	5	6	8
The chef cooks chicken for the customers	*chicken*	154	0	5	3	10
The happy girl rocks forwards and backwards on the rocking chair	*forwards*	11	0	6	5	13
The man trains children to play football	*children*	154	0	5	3	9
The thirsty man drinks water with his meal	*water*	1525	8	5	5	8
The mum slices cake into pieces for the party bags	*cake*	254	19	3	4	14
		314.2	**4.6**	**4.5**	**4.65**	**10.95**

Appendix A: Stimuli for experiment 2

Appendix A: Stimuli for experiment 2

Plural (noun)	***Target***	**Freq of target**	**Target neigh**	**Target phonemes**	**Syllables before target**	**Sentence length (syllables)**
There were four bumps along the road	*along*	427	0	4	4	8
There were four coaches sitting in the carpark	*sitting*	203	6	5	5	11
There were six dresses hanging in the wardrobe	*hanging*	62	4	5	5	11
There were nine ducks under the water	*under*	517	0	5	4	9
There were four plants growing in the garden	*growing*	103	2	5	4	10
There were seven stamps left over in the shop	*left*	362	5	4	5	11
There were two watches broken by the boy	*Broken*	200	0	6	5	10
The girl has five drawers filled with clothes in her bedroom	*filled*	114	10	4	5	12
There were two water drops running down the window	*running*	265	4	5	6	12
The teacher blows two whistles loudly at the end of play	*loudly*	59	0	5	7	14
There were two dog leads hanging on the hook	*hanging*	62	4	5	5	10
There were three hammers hooked onto the workshop wall	*hooked*	5	4	4	5	12
The teacher sent four emails quickly after school	*quickly*	195	0	6	7	12
The art gallery had two pictures showing people smiling	*showing*	22	6	4	9	16
There were three tests children had to pass	*children*	2291	0	7	4	9
There were four cooks chopping vegetables in the kitchen	*chopping*	11	6	5	4	13
There were nine rocks falling down the hillside	*falling*	84	3	5	4	10
There were three trains chugging along the railway	*chugging*	0	0	5	4	11
There were four drinks waiting to be paid for	*waiting*	154	7	5	4	10
Mum put two pizza slices carefully on the plate	*carefully*	141	0	5	7	14
		264.4	**3.35**	**4.85**	**5.1**	**11.35**

Appendix A: Stimuli for experiment 2

Third person singular LONG SENTENCES

The small, old and dirty yellow car bumps along the road

The big tall man coaches six football teams

The old, smiling shop keeper dresses happy customers in new clothes

The tall lady with lovely long hair ducks under the door so she doesn't hit her head

The blonde-haired, blue-eyed girl plants green vegetables in her garden

The jolly, laughing postman stamps letters before putting them in the post box

The very important king watches brave knights fighting to protect him

The old grey-haired man draws fish whilst sitting by the pond

The really naughty little boy drops rubbish on the floor

The year seven class teacher whistles loudly at the end of play time

The school's year 2 teacher leads happy children to the playground

The big, tall, strong builder hammers hooks into the wall

The clever and funny teacher emails quiz questions to the children

The very hungry little girl pictures shops filled with sweets

The clever year seven class teacher tests children in school

The big fat chef cooks chicken for the customers

The happy smiling little girl rocks forwards and backwards on the rocking chair

Comprehension questions

(NB: These are the same for the short sentences)

What did the car do along the road?

What does the man do?

What does the shop keeper dress the customers in?

Why does the lady duck under the door?

What does the girl plant in her garden?

Where does the postman put the letters?

Why are the knights fighting?

Where is the man sitting?

What does the boy drop on the floor?

Why does the teacher whistle?

Where does the teacher lead the children?

What does the builder hammer into the wall?

What does the teacher email to the children?

What was in the shops that the girl is picturing?

What does the teacher do?

What food does the chef cook?

What is the girl sitting on?

Appendix A: Stimuli for experiment 2

The tall friendly man <u>trains</u> children to play football

The thirsty old, grey-haired man <u>drinks</u> water with his meal

The friendly and smiling mum <u>slices</u> cake into pieces for the party bags

What sport does the man train the children to play?

What does the man drink with his meal?

What food did the mum slice?

Regular plural LONG SENTENCES

In the countryside, there were four <u>bumps</u> along the road

Last week, there were four <u>coaches</u> sitting in the carpark

In the big room, there were six <u>dresses</u> hanging in the wardrobe

At the river, there were nine <u>ducks</u> under the water

At the house there were four <u>plants</u> growing in the garden

Yesterday, there were seven <u>stamps</u> left over in the shop

Last week, there were two <u>watches</u> broken by the boy

In the house, the girl has five <u>drawers</u> filled with clothes in her bedroom

Every day, the teacher blows two <u>whistles</u> loudly at the end of play

Yesterday, there were two water <u>drops</u> running down the window

In the hallway, that there were two dog <u>leads</u> hanging on the hook

In the factory, there were three <u>hammers</u> hooked onto the workshop wall

Last week, the teacher sent four <u>emails</u> quickly after school

Comprehension questions

(NB: These are the same for the short sentences

What was there along the road?

What was sitting in the carpark?

What was hanging in the wardrobe?

How many ducks were under the water?

What was growing in the garden?

How many stamps were left over in the shop?

What did the boy break?

What was in the drawers?

What does the teacher blow?

Where were the water drops running?

What was hanging on the hook?

Where were the hammers hooked?

What did the teacher do after school?

Appendix A: Stimuli for experiment 2

At the weekend, the art gallery had two <u>pictures</u> showing people smiling	How many pictures showed people smiling?
In the year 6 class, there were three <u>tests</u> children had to pass	What year group was the class?
In the restaurant, there were four <u>cooks</u> chopping vegetables in the kitchen	What were the cooks chopping?
In the countryside, there were nine <u>rocks</u> falling down the hillside	What was falling down the hillside?
Yesterday, there were three <u>trains</u> chugging along the railway	How many trains were chugging?
In the restaurant, there were four <u>drinks</u> waiting to be paid for	What needed to be paid for?
At Dinner time, mum put two pizza <u>slices</u> carefully on the plate	What was for dinner?

Appendix A: Stimuli for experiments 3 and 4. *NB: The stimuli controls such as frequency and number of syllables can be found under experiment 2*

Past tense **Target**	**Sentence (critical word underlined) and comprehension question**
along	Yesterday, the car bumped along the road *Qn: What did the car do?*
brave	Yesterday, the king watched brave knights fighting to protect him *Qn: Why were the knights fighting?*
chicken	Yesterday, the chef cooked chicken for the customers *Qn: What food did the chef cook?*
children	Yesterday, the man trained children to play football *Qn: What did the man do yesterday?*
children	Last week, the teacher tested children in school *Qn: What did the teacher do last week?*
forwards	Last week, the girl rocked forwards and backwards on the rocking chair *Qn: What did the girl do last week?*
green	Last week, the girl planted green vegetables in her garden *Qn: Where did the girl plant the vegetables?*
happily	Yesterday, the clown joked happily with the children *Qn: Who did the clown joke with?*
happy	Yesterday, the shop keeper dressed happy customers in new clothes *Qn: What did the shop keeper do yesterday?*
hooks	Yesterday, the builder hammered hooks into the wall *Qn: What did the builder do yesterday?*
loudly	Last week, the teacher whistled loudly at the end of play time *Qn: When did the teacher whistle?*
Outside	Yesterday, the bus stopped outside school *Qn: Where did the bus stop?*
quiz	Last week, the teacher emailed quiz questions to the children *Qn: What did the teacher email to the children?*
rubbish	Yesterday, the boy dropped rubbish on the floor *Qn: What did the boy do with the rubbish?*
six	Last week, the man coached six football teams *Qn: What did the man do last week?*
under	Last week, the lady ducked under the door way *Qn: Who ducked under the door way?*

Appendix A: Stimuli for experiments 3 and 4. *NB: The stimuli controls such as frequency and number of syllables can be found under experiment 2*

Third Person	
Target	**Sentence (critical word underlined) and comprehension question**
along	Every week, the car <u>bumps</u> along the road *Qn: What does the car do every week?*
brave	Every day, the king <u>watches</u> brave knights fighting to protect him *Qn: What does the king watch every day?*
chicken	Every day, the chef <u>cooks</u> chicken for the customers *Qn: How often does the chef cook chicken?*
children	Every day, the man <u>trains</u> children to play football *Qn: What does the man do every day?*
children	Every week, the teacher <u>tests</u> children in school *Qn: Who does the teacher test?*
forwards	Every day, the girl <u>rocks</u> forwards and backwards on the rocking chair *Qn: What sort of chair is the girl sitting on?*
green	Every week, the girl <u>plants</u> green vegetables in her garden *Qn: How often does the girl plant vegetables?*
happily	Every week, the clown <u>jokes</u> happily with the children *What does the clown do?*
happy	Every day, the shop keeper <u>dresses</u> happy customers in new clothes *Qn: How often does the shop keeper dress customers in new clothes?*
hooks	Every week, the builder <u>hammers</u> hooks into the wall *Qn: What does the builder hammer into the wall?*
loudly	Every day, the teacher <u>whistles</u> loudly at the end of play time *Qn: When does the teacher whistle?*
Outside	Every week, the bus <u>stops</u> outside school *Qn: How often does the bus stop outside school?*
quiz	Every week, the teacher <u>emails</u> quiz questions to the children *Qn: Who does the teacher email?*
rubbish	Every day, the boy <u>drops</u> rubbish on the floor *Qn: What does the boy drop on the floor?*
six	Every week, the man <u>coaches</u> six football teams *Qn: How often does the man coach the football teams?*
under	Every day, the lady <u>ducks</u> under the door way *Qn: How often does the lady duck under the door way?*

Appendix A: Stimuli for experiments 3 and 4. *NB: The stimuli controls such as frequency and number of syllables can be found under experiment 2*

Plural **Target**	**Sentence (critical word underlined) and comprehension question**
Along	There are four bumps along the road *Qn: What are there along the road?*
Broken	There are two watches broken by the boy *Qn: Who broke the watches?*
Children	There are three tests children have to pass *Qn: How many tests do the children have to pass?*
Chugging	In the countryside, there are three trains chugging along the railway *Qn: How many trains are there?*
Falling	In the countryside, there are nine rocks falling quickly down the hillside *Qn: Where are the rocks falling?*
Growing	There are four plants growing in the garden *Qn: What are growing in the garden?*
Hanging	There are six dresses hanging neatly in the wardrobe *Qn: Where are the dresses hanging?*
Happily	The funny clown tells two jokes happily to the children *Qn: How many jokes does the clown tell?*
Hooked	There are three hammers hooked onto the workshop wall *Qn: Where are the hammers hooked?*
Loudly	The friendly teacher blows two whistles loudly at the end of play *Qn: What does the teacher do at the end of play?*
Outside	There are three bus stops outside school *Qn: What is there outside school?*
Quickly	The clever teacher sent four emails quickly after school *Qn: What did the teacher do after school?*
Running	There are two water drops running down the window *What was running down the window?*
Sitting	There are four coaches sitting in the carpark *Qn: Where are the coaches?*
Under	At the lake, there are nine ducks under the water *Qn: Where are the ducks?*
Vegetables	There are four cooks chopping vegetables in the kitchen *Qn: Where are the cooks?*

Appendix B: Coding script for PRAAT to generate signal-correlated noise

```
#This script generated signal correlated noise
#for all selected sounds

nOfSounds = numberOfSelected("Sound")
if nOfSounds < 1
  exit  select at least 1 sound
endif

for s from 1 to nOfSounds
        name's'$ = selected$("Sound",'s')
        snrSound's' = selected("Sound",'s')
endfor

for snd from 1 to nOfSounds
        name$ = name'snd'$
        snrSound = snrSound'snd'
        select 'snrSound'
        Copy... 'name$'snr
        #calculate the number of samples to be inverted
        n = Get number of samples
        half = round(n/2)
        printline 'n' samples in sound 'name$'
        #make an array for all samples
        #and set all values to one
        for i from 1 to n
          nogniet'i' = 1
        endfor

        #for half of the samples
        for i from 1 to half
              #find a sample that has not yet been inverted
              repeat
                s = floor(randomUniform(1,n))+1
              until nogniet's'
              nogniet's' = 0
              #invert this sample
              Formula... if col = s then self[s] * -1 else self fi
        endfor
endfor
```

Taken from: http://www.holgermitterer.eu/HM/signal_correlated_noise.praa

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