Perceptual and Cognitive Processing Limitations in Specific Language Impairment

Marianna Hayiou-Thomas

Lincoln College, University of Oxford

Thesis submitted for the degree of Doctor of Philosophy

Trinity Term 2002

Table of Contents

Acknowledgements

First and foremost thanks go to my supervisors, Dorothy Bishop, Kim Plunkett, and - for the first three studies especially - John Stein. They have provided unfailing inspiration and guidance throughout my time here, and I am fortunate to have been their student. I have also benefited from being part of not one, but two dynamic and exciting research groups: members of the Babylab and OSCCI, past and present, have taught me a lot and have provided not only academic sustenance but also friendship.

The resources of the University of Oxford, and the Department of Experimental Psychology in particular, must be hard to match, and I have very much enjoyed the opportunity to work here. Peter Hansen and Caroline Witton, in Physiology, wrote the software for Studies 1 and 2 respectively, for which I am very grateful. Dorothy Bishop wrote the software for the Dinosaur, Monster and Bart Simpson games, which made testing fun as well as effective. I would also like to thank Jennifer Utman, who generously gave me free use of her state-of-the-art sound recording and editing facilities.

Without the children who participated in my studies, this research would not have been possible. My thanks go to them, their parents, and the staff at the schools and Language Resource Bases I visited, for making me welcome and giving so generously of their time. These included the LRBs at Rose Hill First school and Donnington Middle school in Oxford, the Northern Language Resource Base in Banbury, and Blossom House school in London; also West Kidlington Primary, St. Andrews CE First school, and Wolvercote First school in Oxford, and especially Rush Common Primary and Dunmore Infant's schools in Abingdon.

Asma Siddiki and Carmel Houston-Price, co-D.Phil.ers and two thirds of the ACE team, have made my graduate years at Oxford very happy ones - their friendship has been a source of comfort as well as much entertainment.

Nearly last, but very far from least, I must record a heartfelt debt of gratitude to my parents, whose unstinting encouragement and support has enabled me to come this far. Finally, this thesis is dedicated to my husband, Edwin. It is ironic that, though language has become our stock-in-trade, in this case words are altogether insufficient.

Short Abstract

Perceptual and Cognitive Processing Limitations in Specific Language Impairment

Marianna Hayiou-Thomas

Lincoln College, University of Oxford

Thesis submitted for the degree of Doctor of Philosophy, Trinity Term, 2002

The experiments presented in this thesis explored the possibility that an underlying cause of specific language impairment (SLI) may be a deficit in perceptual or cognitive information processing.

The first three studies tested the hypothesis that children with SLI have impaired perception of the dynamic elements of visual and auditory stimuli, as proposed in the magnocellular hypothesis for developmental dyslexia. The experimental predictions were that a) children with SLI would have poor sensitivity to coherent motion (but not coherent form) stimuli relative to chronological-age matched controls; b) children with SLI would have poorer sensitivity than controls to slow (but not fast) rates of frequency modulation in a tone; c) sensitivity to slow rates of frequency modulation (FM) would correlate with children's performance on a set of tests of phonological skill. Overall, these predictions were not corroborated by the results, and the conclusion drawn from this set of studies is that a magnocellular impairment of the type reported in dyslexia is unlikely to be a causal factor in SLI.

The second three studies used a grammaticality judgement task to focus on inflectional morphology, an area of language which poses particularly marked difficulty for many children with SLI. The findings from Study 4 suggested that children's performance on the grammaticality judgement task overall was strongly related to phonological discrimination ability, but was unaffected by the specific inflectional allomorph tested. The final two studies manipulated the information processing load of the grammaticality judgement task, in Study 5 to simulate (successfully) SLI-like performance in a group of typically developing children, and in Study 6 to attempt (unsuccessfully) to improve performance in a group of children with SLI.

These results are compatible with the idea that the profile of language difficulties experienced by many children with SLI is due to a processing deficit in the early stages of language acquisition which interrupts the establishment of robust linguistic representations. The nature of this processing deficit is as yet unclear, though the current findings do not support the suggestion of a central auditory impairment. It is possible that a number of distinct deficits, such as poor phonological memory or reduced speed of processing, may produce a broadly similar linguistic profile in different individuals.

Long Abstract

Perceptual and Cognitive Processing Limitations in Specific Language Impairment

Marianna Hayiou-Thomas

Lincoln College, University of Oxford

Thesis submitted for the degree of Doctor of Philosophy, Trinity Term, 2002

Specific language impairment, or SLI, refers to abnormally poor language development, despite apparently normal nonverbal ability and hearing, and in the absence of neurological damage or psychiatric trauma. The cause of SLI is therefore something of a mystery, and is the topic of very lively research. SLI is a highly heterogeneous disorder, varying across individuals and also over the course of development; however, common characteristics include an impoverished vocabulary - relative to chronological and mental age - and a particularly marked difficulty with morphosyntax. Many children with SLI are also characterised by some level of phonological deficit, and in all these domains the difficulty often occurs in both receptive and expressive language.

The theoretical accounts which have been put forward to explain SLI can be classified broadly as 'linguistic' versus 'processing' accounts. The former are focused largely on the grammatical deficits in SLI and attribute these to a primary impairment in the representation of linguistic knowledge. A key assumption underlying this approach is that the mental representation of language - and specifically of grammar - is modular, and that as such it operates independently of other cognitive domains. In contrast, processing accounts of SLI reject the notion that a grammatical deficit can occur in isolation, and suggest instead that the proximal cause is in the processing rather than the representation of information; variants of the processing accounts differ in the level of information processing on which they focus. For example, the auditory deficit hypothesis suggests a perceptual deficit in the analysis of auditory information, which has a deleterious effect on speech perception and subsequent language development. The speed-of-information-processing account, on the other hand, emphasises cognitive rather than perceptual processing and suggests that individuals with SLI are slower than most at analysing higher levels of non-linguistic and linguistic information.

The experiments described in this thesis are an exploration of processing deficit explanations of SLI, at both the perceptual and cognitive levels. The first three experiments are based in the magnocellular theory of developmental dyslexia, which proposes that a neurodevelopmental deficit in the processing of dynamic stimuli - across sensory domains - underlies the literacy difficulties associated with dyslexia. It is argued

that an insensitivity to the dynamic elements in sound may translate into impoverished speech perception, which in turn may lead to the phonological impairment reported in dyslexia. In both the visual and auditory domains, it has been demonstrated that individuals with dyslexia tend to have higher thresholds than controls (that is, lower sensitivity) for the detection of dynamic stimuli. Given the reportedly high degree of overlap between SLI and dyslexia, Studies 1, 2, and 3 attempted to replicate these findings in a group of children with SLI.

The first study targeted the visual domain, and psychophysical thresholds were obtained for children's detection of coherent motion. The task involved Random Dot Kinematograms, in which a certain proportion of dots in a constantly moving background appear to move in a given direction; the smaller the number of dots an individual needs to detect the direction of this coherent motion, the higher his or her sensitivity. It was predicted that children with language impairment would have poorer coherent motion detection than chronological-age and nonverbal ability matched controls. A control task involving the perception of coherent form (in which the orientation of static lines indicated a circle) was also included, and it was predicted that there would be no group differences in this task, as the hypothesised deficit is restricted to dynamic stimuli. The results were counter to the experimental predictions, in that the children with language impairment did not differ from controls in their perception of either coherent motion or coherent form.

The second and third studies targeted the auditory domain, and thresholds were obtained for the detection of frequency modulation (FM) in a tone. In FM, the frequency of the tone changes periodically over the course of the stimulus; at slow rates (for example 2 Hz, or cycles per minute) the modulation can be tracked by the listener, while at fast rates (e.g. 240 Hz) the change is too rapid to be perceived as a dynamic stimulus. In parallel with the visual experiment, it was predicted that children with language impairment would be poorer than controls at perceiving the dynamic stimulus, i.e. the slow rate of modulation, but not the fast rate. On the basis of research in dyslexia, it was additionally predicted that sensitivity to slow rates of FM would correlate with performance on phonological tasks such as nonword repetition, nonword reading, and phonological discrimination. In Study 2 there were trends in the predicted directions, both in terms of group differences on FM detection as well as in terms of correlations with phonology; however, these were statistically non-significant. This may have been due to the large number of unreliable thresholds which had to be discarded, and which were probably the result of a task which was insufficiently motivating to hold children's attention effectively.

Study 3 attempted to clarify whether the trends seen in Study 2 towards poor FM detection in the SLI group were reliable. In addition to the 2 Hz and 240 Hz rates of FM used previously, this study also included a 20 Hz rate of FM, which is a rate of frequency change more likely to be directly relevant to speech perception. A child-friendly task, referred to as the 'Dinosaur Game', was developed and used for data collection; this proved an effective way of obtaining reliable thresholds. Contrary to the experimental predictions, the performance of children with language impairment on the slow rate FM detection tasks was no worse than that of control children. Also counter to predictions, FM sensitivity did not correlate with performance on tasks tapping phonological skill.

The results of the first three experiments do not support the hypothesis of a magnocellular deficit in SLI, of the type reported in dyslexia. The implications of this conclusion are twofold: firstly, that an auditory deficit, at least in tracking the frequency changes of sound stimuli, is unlikely to underlie the phonological and higher language difficulties seen in SLI. Secondly, that SLI and dyslexia are unlikely to share a common causal mechanism, and it may be erroneous to view them as lying on a continuum of severity of language disorder as is increasingly assumed in the research literature.

The fourth study was a move away from looking for a non-speech auditory deficit underpinning speech perception in SLI, and instead focused on elements of speech itself. It was hypothesised that the phonological structure of inflectional allomorphs, specifically the allomorphs of the English regular past tense inflection, would affect children's sensitivity to them. A grammaticality judgement task was devised, in which an obligatory inflection - the /«d/, /d/, or /t/ allomorph - was missing from half the sentences. In addition, a set of sentences with missing prepositions (*in*, *on*, or *at*) was included as a control condition. The predictions were a) that children with SLI would make more errors than control children on past tense but not prepositions sentences; b) that all children (but particularly the SLI group) would be more likely to accept sentences whose verbs were missing an obligatory inflection with low perceptual salience /t/ than sentences missing an inflection with high perceptual salience (/«d/; /d/ was predicted to fall in between); and c) that performance on the grammaticality judgement task would correlate with performance on independent phonological tasks. The results partially confirmed the experimental predictions: although there was no effect of allomorph salience, children with SLI made significantly more errors than controls on all past tense but not prepositions sentences. Furthermore, grammaticality judgement scores correlated significantly with phonological discrimination scores even when the effects of age and vocabulary level were controlled for. This relationship between phonology and inflectional morphology is not compatible with the idea of an isolated and independent grammatical deficit.

The final two studies used the grammaticality judgement task developed in Study 4 to explore the idea of a general processing deficit in SLI. Study 5 attempted to 'model' SLI in a group of 6-year old children with typically developing language, by introducing specific cognitive stress factors into the task. At normal speech-rate, all children had near-perfect performance. When the speech signal was compressed to 50% of its original rate, to simulate a reduced speed of processing, children displayed the same pattern of errors that is reported in SLI: good performance on noun morphology (plural *–s*), and very poor performance on verb morphology (past-tense *–ed*, and 3rd person singular *–s*). A similar pattern was found when the memory load was increased by adding redundant verbiage to the sentences. The finding that an SLI-like pattern of performance can be induced in children with intact linguistic systems by increasing processing demands, supports the idea that a processing deficit may underlie language performance in SLI. However, it does not demonstrate that such a deficit is actually present in children with SLI, nor that it contributes to their impaired language development.

Study 6 tested the hypothesis that alleviating the putative speed of processing deficit may improve language performance in children with SLI. Accordingly, the sentence-speeding manipulation in Study 5 was reversed, and sentences were expanded by 30%; an additional manipulation was the addition of a 500 ms pause following the target verb. The inflection tested was past tense *-ed*, and prepositions sentences were again included as a control condition. Neither slowed speech nor the inserted pause had any effect on children's grammaticality judgements. However, children with SLI did demonstrate a selective difficulty with past tense but not prepositions sentences, which was not apparent in either chronological-age matched controls, or younger language-age matched controls. This finding suggests that language-impaired children's representations of the past tense are indeed compromised; this is inconsistent with an extreme version of a processing deficit account of SLI, in which linguistic competence is intact and the main difficulty is due to (reversible) on-line performance limitations. However, the issue of how the representations came to be impaired is an open question; the results of Study 6 are compatible with the suggestion of a processing deficit at early stages of language acquisition, which impacts negatively on the development of the past tense paradigm.

The results of the experiments reported in this thesis suggest that the phonological deficits often exhibited by children with SLI are not due to impaired perception of the dynamic changes in sound; nor does there appear to be a more widespread impairment in the functioning of the magnocellular system, of the type reported in developmental dyslexia. Further, the marked difficulties exhibited by many English-speaking children with SLI in the field of inflectional morphology cannot be explained simply in terms of the perceptual salience of the inflections. However, there is a consistent and potentially causal relationship between sensitivity to phonological discrimination and sensitivity to obligatory inflectional morphemes in the context of a grammaticality judgement task. Within the narrowly-specified field of inflectional morphology, an SLI-like profile of performance can be simulated in children with typically developing language, with the introduction of speech-compression and excess memory-load to a grammaticality judgement task. This is consistent with the idea that either reduced speed of processing, or poor phonological memory, may underlie real cases of SLI. However, the finding that reducing the speed of processing demands of the task do not improve performance in a group of children with SLI, suggests that any speed of processing deficit which may have adversely impacted on these children's language development, must have done so at an earlier stage in language acquisition.

Chapter 1: General Introduction

An estimated 3-10% of young children have impaired language development which cannot be attributed to general cognitive deficits, hearing impairments, psychiatric problems or frank neurological damage. These children are referred to as having specific language impairment, and the underlying cause of SLI is a hotly debated topic of research.

Given the exclusionary criteria used to identify children with SLI, it is unsurprising that these children constitute a highly heterogeneous group, with a wide range of language difficulties. Nonetheless, a child with SLI will often have a smaller vocabulary than would be expected for his or her age and intelligence (which will be age-appropriate), and particular weaknesses in grammar and phonology; comprehension is below age-level, but production is even poorer. Reading difficulties often emerge in the school years, and although language problems might partially resolve, it is unlikely that they will disappear completely even in adulthood. More boys than girls seem to be affected, with an estimated ratio of about 3:1 (Robinson, 1987), and there is mounting evidence of a significant genetic contribution to the disorder (Tomblin, 1996; Plomin, 2000).

Subtypes of SLI

There have been several attempts to specify subtypes of SLI, although there are no established diagnostic divisions as yet. Using factor analysis, Aram and Nation (1975) identified six patterns based on a set of tests of comprehension, production and repetition for phonology, syntax and semantics. One group performed poorly on all tests. A second group performed moderately well on both production and comprehension tasks. The third and fourth groups had greater difficulty with production than comprehension, with varying degrees of disparity between the two.

The fifth group had particular difficulties with phonology and grammatical production, while the sixth had an unexpected strength in repetition tasks. A simpler, but not dissimilar, classification was suggested by Wolfus, Moscovitch, & Kinsbourne (1980), who characterised one group as having particular deficits in the production of phonology and syntax, and one group as having global deficits in both comprehension and production. It should be noted that both these studies had a relatively small number of children on which to base their categories (47 children for Aram and Nation, 19 for Wolfus et al.).

Clinical judgements offer an alternative method of identifying subtypes, as exemplified by Rapin and Allen (1983) in the USA, and Bishop and Rosenbloom (1988) in the UK (note that Rapin and Allen's classification system is descriptive of communicative problems per se, regardless of origin, whereas Bishop and Rosenbloom's conforms to the exclusionary criteria for SLI). Both of these classification systems suggested three categories which describe deficits with the form and structure of language: "phonologic-syntactic", in which relatively mild comprehension difficulties are coupled with particular problems in the production of phonology and morphosyntax; "lexical-semantic", in which word-finding problems seem to dominate; and "verbal auditory agnosia", rarely seen, in which there is an extremely severe deficit in both comprehension and production.

Most recently, Conti-Ramsden, Crutchley and Botting (1997) identified five unique profiles of difficulty in a large sample of children attending language units in UK schools. Children described as having severe Expressive and Receptive Impairments performed poorly on all language tests administered, including phonology and articulation, understanding and use of grammar, object naming, story retelling, and word reading. This subtype constituted the single largest group of children (84 out of the total 242). A second group of children were described in terms of Complex Multi-word Deficits, and had difficulties with word reading and retelling a story, as well as the comprehension of grammar, but had relatively good phonology and expressive vocabulary. A third group was identified as having Expressive-Phonological Impairments; these children had adequate expressive vocabulary and comprehension of grammar, but poor word reading, phonology and story retelling. The fourth group were children with Phonological and Single Word Deficits; these children had poor expressive vocabulary but were otherwise similar to the Expressive-Phonological Impairments group. The fifth and final group outlined by Conti-Ramsden et al. described a group of children who had adequate phonology, expressive vocabulary, comprehension of grammar, and word reading, but who were poor at story retelling, and were considered by their teachers to have difficulties with the social use of language. These children were referred to as having Pragmatic Language Impairments.

Rapin and Allen (1983) also described a "semantic-pragmatic" disorder, in which there is socially and pragmatically abnormal use of language, despite a relatively unimpaired grasp of the structure of language. These children display some characteristics usually associated with autism, and the region of overlap between autism and language impairment in this population is the subject of an increasing amount of research (Bishop, 1998; Bishop & Norbury, 2002). The term Pragmatic Language Impairment (PLI) is rapidly gaining acceptance as a useful descriptor.

Theoretical approaches to SLI

The term 'specific language impairment', which is now almost universally accepted and utilised, contains some strong implications about the nature of the disorder and its underlying causes. Ironically, given its name, one of the major debates regarding explanatory causes of SLI centres around the question of how specifically linguistic it really is.

One of the main theoretical accounts for SLI is rooted in the linguistic framework of generative grammar and - unsurprisingly - attributes the children's problems to a deficit in linguistic (i.e grammatical) knowledge. An important assumption of this approach is that the mental representation of language is modular (Fodor, 1983) and operates independently of other cognitive functions. On this view it is indeed possible to have a truly specific linguistic deficit.

The alternative type of approach suggests a deficit in processing rather than knowledge, which while non-linguistic in itself has particular impact on language functioning. This approach views language as dynamic and distributed in its nature and inherently interactive with many other elements of cognition. On this view, a grammatical deficit is unlikely to occur in isolation, and will be expected to be preceded by, or to co-occur with, a deficit in other elements of language or cognition.

Processing deficit approaches can be broadly subdivided into 'general processing' and 'specific processing' accounts. In the former, the notion of a general resource underlying all cognitive processing is invoked, which can be described in terms of space, energy, or time (Kail & Salthouse, 1994): a limitation in this general resource results in the breakdown in the performance of tasks which draw too heavily on it. Language is a complex operation which requires analysis of rapidly incoming signals, encoding and storage of large amounts of multi-layered information (phonological, lexical, semantic, syntactic, pragmatic), and retrieval and production of this same information in a fast and creative manner. It is precisely the kind of task which should suffer in the face of limited processing capacity. At the same time, any other task which makes similarly complex demands should also suffer, and the presence in SLI of deficits in demanding motor or memory tasks, for example, is crucial to the arguments levelled by the 'general processing deficit' approach.

The 'specific processing deficit' approach, on the other hand, suggests a deficit in specific resources or processes which are necessary to language learning and functioning. For instance, impaired verbal short-term memory could reduce the rehearsal of phonological representations and thus interfere with the storage of newly learnt linguistic material (Gathercole & Baddeley, 1990). A deficit in the accurate discrimination and categorisation of rapidly presented auditory material - whether verbal or non-verbal - could plausibly impact on speech perception, which could easily impact negatively on early language learning (Tallal & Piercy, 1973a, 1973b; Tallal, 1993).

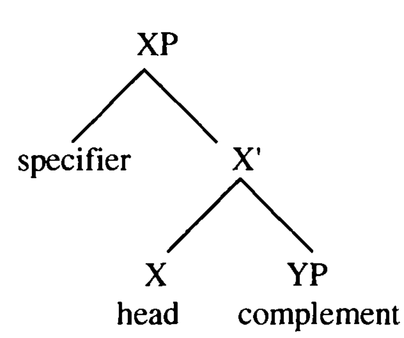
The experiments presented in this thesis are based in the perspective of processing deficit accounts of SLI, with the first set of studies focused on a possible specific perceptual deficit, and the second set focused on the possibility of a higher-level, general processing deficit. In the following sections, however, I discuss some of the arguments and evidence brought forward for both linguistic and processing accounts of SLI.

Linguistic arguments

The version of generative grammar on which several theories of SLI are based is the 'principles and parameters' framework (Chomsky, 1981, 1986). Language learning is viewed as a process of hypothesis generation and testing, aimed at uncovering the grammatical rules which underlie language. A major assumption is that the child does not receive any negative feedback regarding her language - parents do not make overt contrasts between grammatical and ungrammatical forms (Grimshaw & Pinker, 1989). The result is that the child has an apparently intractable 'learnability' problem: she is faced with grammatical forms that could have been generated by any of a large array of rules, but has been provided with none of the negative evidence which would enable her to discard the rules illegal in natural language.

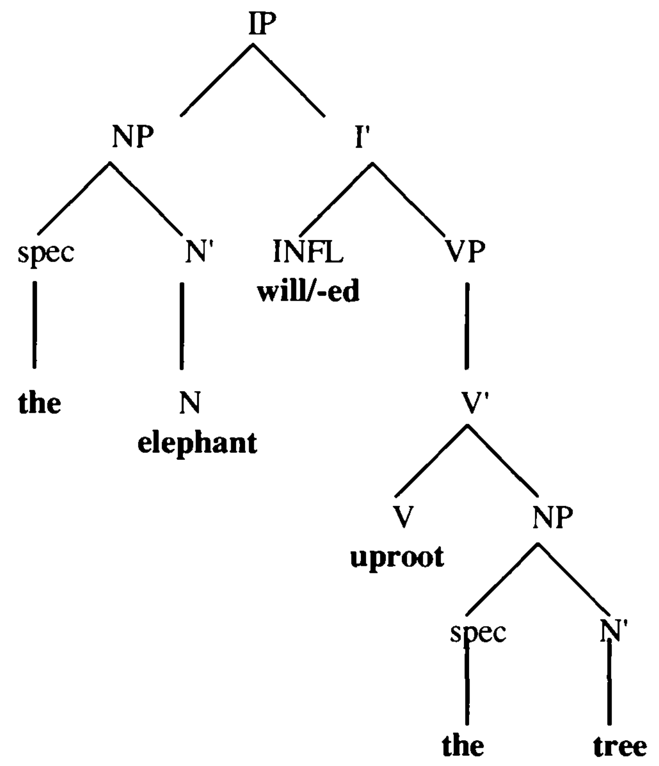
The proffered solution to this problem is that the child has innate constraints or 'principles' which limit the number of grammatical hypotheses which are permissible in natural language. However, these principles cannot be too detailed and specific, since the child must be able to learn any of the thousands of human languages, which differ significantly from one another. Though these differences often seem random, the fact of the matter (at least according to Universal Grammar) is that the world's languages vary systematically according to sets of characteristics, or 'parameters'. The setting of the correct parameters for a particular language is triggered by exposure to appropriate input.

A further important element in this linguistic framework is the distinction between the surface form of a sentence and its underlying grammatical structure. This underlying structure is often described in terms of X-bar syntax, which proposes that all phrases share the same hierarchical structure as follows:



Any phrase can thus be decomposed into three basic elements: a specifier, a head, and a complement, of which only the head is obligatory. When the complement is present it has the same X-bar structure. Phrases can belong to lexical categories such as noun, verb, preposition and adjective, with their respective phrasal projections

NP, VP, PP and AP. Alternatively, they may belong to a functional category such as complementiser, inflection and determiner, with phrasal projections CP, IP and DP. Because the basic elements comprising the underlying structure of a phrase are so abstract, they can be used to describe a phrase of any level of complexity, including a complete sentence.



The functional categories can be elaborated such that the properties of grammar that are associated with inflectional phrases are referred to as the I-system, and similarly complementisers and determiners have the C- and D-systems.

The I-system is particularly relevant to verb morphology. The head I position of IP carries modal auxiliaries (e.g. can, will: *The elephant* ***will*** *uproot the tree*) which have features of tense and agreement (that is, I is in finite form). If I is in the infinitive, then I is occupied by *to* (*(I want) the elephant* ***to*** *uproot the tree*). If I is empty, then it can be filled by moving auxiliary *be* or *have* or copula *be* from the head of the complement, in this case a VP (*The elephant* ***is*** *uprooting the tree*). If there is no such auxiliary, then the tense and agreement features of I can be moved to the head of the VP and take the form of an inflection (*The elephant* ***uprooted*** *the tree*).

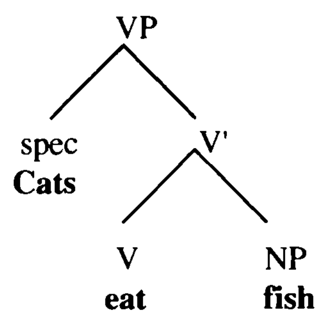
The implications of the I-system go beyond verbs. The specifier position of I accepts the grammatical subject of the sentence, and provides it with the necessary case (thus, *the elephant* is in the nominative case, and could be replaced by the nominative pronoun *he*). Similarly, in passive sentences the grammatical subject also goes to the specifier position of the IP to receive case, though being in underlying structure the theme and having previously occupied a post-verbal position, it leaves a trace coindexed with itself (*The tree$_i$ was uprooted by the elephant (trace of* ***tree$_i$***), with subscript *i* marking indexing). So it can be seen that as regards features of tense and case marking, the I-system is vital.

The C-system, at least in English, is particularly relevant for questions. The head C position accepts auxiliaries that are moved from I (***Is*** *Ezekiel watching Delilah?*). Similarly, the specifier position of CP accepts the *wh-* word moved from its base position, where it leaves a trace (***Why*** *is Ezekiel watching Delilah (trace of why) ?*)

Finally, the D-system is the locus of the articles *a* and *the*, as well as prenominal determiners such as *this* and *that*. The genitive case is also assigned to the D-system, so that the inflection *'s* (*Jenny's avocado-tree*) and prenominal possessives (***her*** *avocado-tree*) act within a DP.

Functional category deficit

One of the hypotheses for a linguistic deficit in SLI is the proposal that individuals with SLI have difficulty with the acquisition of functional categories (Eyer & Leonard, 1995; Guilfoyle, Allen & Moss, 1991; Leonard 1995). This is based on the idea that young normally-developing children don't include functional categories in their grammar until about two years of age (Radford, 1990). According to this idea, the phrase *Cats eat fish* would have the following structure:



This structure is comprised entirely of lexical categories; specifically, it is missing an IP. Given the lack of I, the verb cannot receive tense and agreement features; also, there is no movement of the subject. In the cases where a very young child's utterance sounds as though it contains a functional category, it is argued that the utterance is an unanalysed lexical category, so that what looks like an inflection is actually part of a memorised lexical 'chunk' (Leonard, 1998).

This account would fit in with data showing that English-speaking children with SLI use grammatical morphemes in obligatory contexts much less frequently than do MLU controls. These morphemes include noun plural inflection, third-person singular verb inflection, regular past inflection, and copula and auxiliary *be* forms, as well as infinitival *to* and the complementiser *that* (Leonard, Bortolini, Caselli, McGregor & Sabbadini, 1992; Rice, Wexler & Cleave, 1995). However, though children with SLI use them less frequently, they do use them occasionally (and then often correctly): Leonard (1995) found that in every one of the 10 English-speaking pre-schoolers with SLI examined, there was:

> evidence of at least 1) articles; 2) the prenominal determiners *this* and *that*; 3) three different pronominal possessive forms; 4) the third singular *-s* and/or regular past *-ed*; 5) some form of copula *be*; 6)some form of auxiliary *be*; 7) the modal forms *can* and *can't*; 8) the auxiliary form *don't*; 9) three different pronouns reflecting nominative case; 10) auxiliary inversion and 11) an utterance-initial *wh-* phrase that could not be construed as the subject of the sentence. (reported in Leonard, 1998, p. 221)

Therefore, although functional categories may be weak, they cannot be altogether missing; this implies that when inflections are used, they cannot be dismissed as simply being part of an unanalysed lexical chunk.

Extended Optional Infinitive

Another linguistic deficit account also takes its root in the pattern of normal linguistic development. Rice and colleagues' Extended Optional Infinitive account is based on Wexler's (1994, 1996) observation that tense-marking is a part of the grammar that is particularly slow to emerge in children with normal language development. This period, in which the marking of tense is an optional feature in the child's grammar, is called the Optional Infinitive stage. Centred as the hypothesis is on acquisition of tense, it makes specific predictions about the types of morphemes that will be affected: specifically, the past tense *-ed*, the third person singular *'s*, *be*, and *do*.

As regards SLI, Rice suggests that affected children use this immature grammar for longer than unaffected children, hence the name Extended Optional Infinitive stage. According to Rice & Wexler (1996), children with SLI have less than 50% correct performance on use of tense-marking morphemes compared to over 90% for age-matched controls. It is argued that on the basis of the use of these morphemes, children with SLI can be identified with high accuracy. Moreover, in a recently completed longitudinal study (Rice, Wexler & Hershberger, 1998) it was shown that children with SLI did not catch up to their peers in their use of tense-marking morphemes, so that while most children reach adult levels of usage by 5 years of age, one might still hear a child with SLI at age 8 say *Granny see me.*

Problems with tense-marking morphemes were seen not only in production, but also in comprehension as tested by grammaticality judgements, which require the subject to decide whether or not a phrase is well-formed (Rice, Wexler & Redmond, 1999). Further, it is argued that in both production and comprehension, low levels of performance in children with SLI are limited to tense-marking morphemes and do not affect all grammatical morphemes: for instance, acquisition of regular plural *-s* (as in *trees*) is relatively unaffected. The theoretical corollary of this pattern of performance is that "the problem is not a general one of being unable to acquire grammatical rules" (Rice, 2000, p. 24).

Finally, although the main focus of the account is on verb tense, the idea behind the Extended Optional Infinitive account also predicts links between tense and case marking, which in English is most obvious in the use of personal pronouns. This claim is supported by findings that children with SLI mistake case marking more often than their peers (Loeb & Leonard, 1991), and these case errors seem to occur much more frequently when the associated verb does not show tense/agreement marking: *him laugh* is thus more likely than *him laughs* or *he laugh* (Wexler, Schuetze & Rice, 1998).

Working within a modular linguistic framework as it does, the Extended Optional Infinitive account calls for a dichotomy between the mature and immature grammars, immature in this case being optional use of tense-marking. A dichotomy, however, implies that once a language-user has moved past this stage (quoted as age 5 for most children) they should never again regard tense marking as optional. And yet in the studies comparing children with SLI to age- or MLU- (mean length of utterance) matched controls in their use of tense-marking morphemes, the control children do not reach levels of 100% correct performance; instead they hover between about 50% and 80% correct, which while always better than the SLI group is far from perfect.

"Feature blindness" and "rule learning"

The logical extension of taking a Principles and Parameters approach to SLI is to say that at least part of the innate 'grammar module' presumed to be present in linguistically normal individuals, is missing or damaged in individuals with SLI. Such a position seemed to find support in studies of the K-family.

The K-family is famous in the linguistic community for having about half its members, across three generations, affected by a severe form of SLI. The family pedigree with respect to language is compatible with a dominant pattern of inheritance (Hurst, Baraitser, Auger, Graham & Norell, 1990), and it was at one stage proposed that the affected members of the family were, in effect, missing their 'grammar genes'.

The earliest formulation of this idea was the 'feature-blindness' hypothesis (Gopnik, 1990) in which features such as number, aspect, tense and person were described as missing from the individual's underlying grammar altogether. Affected members of the K-family performed poorly on a number of tasks which test for sensitivity to these features. In a past tense-elicitation task, they could not correctly complete a sentence such as: "Every day he kisses his granny. Yesterday he ________ [kissed his granny]". In the wug test (Berko, 1958), they were not able to reliably give the plural form of a novel noun: "This is a wug. These are two ____ [wugs]". In grammaticality judgement tasks which included tense marking, aspect, and number errors, the affected family members were far more likely than the unaffected family members to accept as correct sentences which were ungrammatical. However, although the K-family were certainly found to have problems with these grammatical features, they were not all-pervasive: when asked to "point to the books", for instance, they were able to point correctly to a picture with many books instead of a picture with a single book (Gopnik, 1990).

Findings like these led to a reformulation of the hypothesis: the language profiles of individuals with SLI are due to their inability to acquire implicit rules to mark tense, aspect, number, person, case etc. (Gopnik & Crago, 1991; Ullman & Gopnik, 1994). This is meant to result in underspecified morphological paradigms, and a lack of distinction between roots and inflectional endings. Cross-linguistic evidence which is cited in support of this hypothesis includes compounding in Greek (Dalalakis, 1999). Greek nouns in isolation never appear as bare stems (that is, the root is always inflected); when two nouns are compounded, however, the bare roots are concatenated, and an inflection is attached to the end of the compound stem. In order to compound correctly, therefore, one must be able to extract the bare root from all the inflected exemplars that have been heard; in other words, the boundary between root and inflections must be distinctly represented. Greek-learning children with SLI are unable to produce novel compounds (of real nouns) reliably, with frequent over- or under- extensions of the real root, so that instead of the target form /anthropo-fagos/ (man-eater), they might produce /anthro-fagos/. Their error rate of 84% contrasts markedly with that of younger controls (5%), and age-matched controls (1.25%).

Further evidence which Gopnik and colleagues cite to support the hypothesis of underspecified morphological paradigms is data from a lexical decision task, in which language-impaired individuals did not show the normal pattern of slower responses to inflected vs. uninflected novel words (Gopnik, 1996). This was interpreted as a lack of sensitivity to the presence of the inflection.

Language-impaired individuals also showed a frequency effect in producing the past tense form of real verbs, such that high-frequency verbs were more likely to be correctly inflected (Gopnik, Dalalakis, Fukuda, Fukuda & Kehayia, 1996).

According to modular theories of inflectional morphology (Pinker, 1999), irregular verbs are rote-learned and stored on an item-by-item basis in an associative memory system, and their retrieval is consequently susceptible to the effects of frequency (more frequent items should be retrieved more quickly and accurately). Regular verbs, on the other hand, should be impervious to the effects of frequency because they are inflected by the implicit default rule "add *-ed*". Therefore, the lack of a frequency effect for regular verbs is taken to indicate the presence of the functioning rule, and conversely the presence of a frequency effect indicates absence of the rule. According to this argument, language-impaired individuals treat regular verbs as if they were irregular, rote-learning the inflected forms instead of abstracting the appropriate linguistic rule. Note that this argument relies heavily on the lack of frequency effects for regular verb inflection in the normal population, but this is a highly contested point, with a number of studies (including some based in the modular perspective) reporting frequency effects for regular verbs (e.g. Beck, 1997).

In short, the "impaired rule learning" hypothesis suggests that though the implicit grammatical rules may be missing, compensation can be achieved either by memorising inflected forms as unanalysed lexical items (so that *play*, *plays*, *played*, *playing* would all be learnt separately) or by applying learned explicit rules (such as *add -ed to describe past events*).

The inefficiency inherent in learning four separate lexical items instead of one 'inflectable' item could explain the lower frequency of use of inflected forms in SLI, as it would take the child much longer to have these forms ready for use. One problem with this explanation is that by adulthood, most of the lexical forms should be more or less learned - and though this is often the case, it is not so with the K-family. Another objection to this argument could be that, if *play*, *plays*, *played*, *playing* are all rote learned and unanalysed, one might expect to see productions of *played* instead of *plays* (substitution) as frequently as *play* instead of *plays* (omission). This is not the pattern that is usually reported. However, this objection rests on the assumption that all rote-learned items have equal status; this is not necessarily the case, as it may be that more frequently heard forms, such as *play* compared to *played*, are more likely to be used.

The alternative, or more likely, complement to the rote-learning strategy is the use of explicit rules in the absence of implicit ones. This suggestion is based on two main observations: overt signs from subjects such as whispering *"add an s"* to themselves, or hesitations; and added endings which do not obey the phonotactic rules of the language, such as pluralising the nonsense word *wug* with an /s/ instead of a /z/. (Goad & Rebellati, 1994). While the first observation is quite striking, the second could as easily be explained by phonological deficits as by grammatical ones (Fee, 1995).

A claim of inability to learn grammatical rules in SLI is threatened when behaviour associated with rule-use is found in individuals with SLI. Thus, over-regularisation, which is often described as over-application of the past-tense rule, should not be found in SLI; such a finding has been reported by Leonard, Bortolini et al. (1992) and Vargha-Khadem, Watkins, Alcock, Fletcher & Passingham (1995). Similarly, if the 'normal' course of language-learning in children with SLI requires them to learn all words as though they were irregulars (rote-learned rather than derived from a rule), they should not have undue problems with irregular inflections; and yet they do (Bishop, 1994; Ullman & Gopnik, 1994; Vargha-Khadem et al., 1995).

Finally, before leaving the rule-learning deficit account altogether, it should be pointed out that it depends entirely - as do all the linguistic deficit accounts of SLI - on the psychological reality of Universal Grammar. If it could be shown (independently of SLI) that language learning does not in fact rely on innate grammatical rules - as, for instance, connectionist theory would argue - any account of SLI which takes the innate 'grammar module' as its underlying assumption would be invalidated. One could speculate that a realistic compromise would entail a view of rules which emerged from language learning, in which case a disrupted learning process would also result in disrupted rules. However, current descriptions by defendants of Universal Grammar depict innately specified rules which unfold ready-made, rather than ones which develop over the course of learning.

Structural relationship accounts

A final linguistic approach to SLI emphasises problems with structural relationships. Clahsen (1989) describes a missing agreement account for both English and German. According to this account children with SLI are proposed to have particular problems with verb inflections (as well as auxiliaries and copula forms) which must agree with the subject according to person and number; a problem also arises with gender and number agreement within the noun phrase. Forms which do not require agreement, such as past-tense inflection or plural morphology, should not be affected. Evidence to support this position was reported by Clahsen, Rothweiler, Woest & Marcus (1992): for example, gender and number agreements in noun phrases was problematic for German-speaking children with SLI, as was the use of case markers for accusative, genitive, and dative. Although verbs were often uninflected, some types of verb morphology, such as participles, were spared. It should be noted that in contrast to a rule-learning deficit account, this description of grammatical weakness in SLI does not posit inability to acquire a morphological paradigm per se, but a somewhat higher-level deficit in relating morphological paradigms correctly.

A somewhat broader account in a similar vein is van der Lely's (1994, 1996; van der Lely & Stollwerck, 1997) representational deficit for dependent relations (RDDR). Here, in addition to problems with agreement she posits problems with specifier-head relations which do not involve subject-verb agreement, such as tense marking (after Rice and Oetting, 1993). Such a deficit would also predict difficulty in assigning thematic roles in the absence of semantic information, i.e. when only syntactic information is available. An example of this is a sentence with a reversible passive: *The boy is chased by the girl* includes no semantic or real-world information about who is doing the chasing, as both are equally plausible (in contrast to *The mouse is chased by the cat* in which it is far more likely that the cat is doing the chasing). A correct interpretation of the reversible passive is dependent on identification of the syntactic relationship between the verb and the two noun phrases; that is, of the syntactic positions Subject and Object, which are themselves determined by case marking. As a representational deficit would predict, children with SLI have trouble comprehending this type of sentence (Bishop, 1982; van der Lely & Harris, 1990).

In further work on passives, van der Lely (1996) found that children with SLI perform more poorly on full passives (e.g. *The teddy was mended by the girl*) compared to short passives (e.g. *The teddy was mended*). This is initially surprising since short passives are considered to have complex noncanonical relations between thematic roles and syntactic function, which should be problematic in SLI. However, if *mended* is interpreted as an adjective rather than a verb, the phrase becomes syntactically much simpler, as it requires only one rather than two thematic roles. Van der Lely reported evidence that children with SLI do tend to adopt an adjectival interpretation of short ambiguous passives: in a picture-pointing task, children with SLI were much more likely than language-matched controls to (legitimately) choose an adjectival interpretation (a picture of a neatly mended teddy on its own) over a passive interpretation (a picture of a girl mending a teddy). They were also more likely than controls to choose an erroneous adjectival interpretation of a short progressive passive (e.g. *The teddy is being mended*).

Pronominal reference is another area in which the predictions of the RDDR account have been tested (van der Lely & Stollwerck, 1997). According to Binding Theory (Chomsky, 1986), reflexives must be locally bound, which means they must have a local antecedent (broadly speaking, a noun phrase in the same clause). In the sentence *Baloo Bear says Mowgli is tickling himself*, the reflexive *himself* can only refer to Mowgli. On the other hand, personal pronouns may not refer to local antecedents, so in the sentence *Baloo Bear says Mowgli is tickling him*, *him* can only refer to Baloo Bear. Although children with SLI performed close to ceiling in a control condition in which semantic cues could be used (e.g. gender), they performed poorly in conditions in which knowledge of binding principles was the only route to a correct interpretation. Thus, given a picture judgement task, they were considerably more likely than language-matched controls to say that *Baloo Bear says Mowgli is tickling him* matched a picture in which Mowgli was shown tickling himself.

It should be noted that the claims of the RDDR extend only to a subset of the SLI population known as Grammatical-SLI, which Van der Lely and Stollwerck (1997) define as children whose "grammatical abilities appear to be impaired over and above any general (secondary) language impairment they may have in, for example, lexical development". Van der Lely, Rosen, and McClelland (1998) presented a detailed description of a boy whose linguistic profile exemplifies G-SLI. AZ was a delayed speaker, and when tested at age 10 had a vocabulary level appropriate for a child about 2 ½ years younger. Relative to his vocabulary level he demonstrated disproportionate difficulty on tests of morphosyntactic ability, on which he scored about 4 ½ years behind age-level. He had great difficulty with a past-tense elicitation task, as well as a grammaticality judgement task involving verb inflection. He also did poorly on the test of pronomial reference described above. In contrast to these grammatical weaknesses, he performed in the normal range on tests of pragmatic language, verbal reasoning, non-verbal transitive inference, and had a non-verbal IQ score of 119. He also had age-appropriate performance on an inspection-time task and showed no deficit in an auditory temporal-order judgement or backward masking task. Van der Lely et al (1998) report similar profiles in a further group of six children, and conclude that:

> ...the results argue for the existence of a genetically determined specialisation of a sub-system in the brain required for grammar and, it appears, for nothing else. (p. 1257)

This strong position is challenged by the findings from a twin-study (Bishop, Bright, James, Bishop, and van der Lely, 2000), in which qualitative markers of G-SLI were derived from a set of language comprehension tests sensitive to G-SLI (including the tests of pronomial reference and passive sentences described earlier). Only a very small subgroup of children scored positively on at least four out of the five indicators of G-SLI, and those who did tended to also show deficits in nonsyntactic language tasks (such as word-finding) and/or nonverbal ability, which is inconsistent with a pure syntactic deficit. In addition, some of the children who met criteria for G-SLI were not considered to be language-impaired in terms of either therapy status or standardised tests. A substantial number of children scored positively on one, two, or three of the G-SLI indictors, suggesting a partial G-SLI deficit. Although this may mean that pure G-SLI is just exceedingly rare, the existence of partial G-SLI does not sit well with the all-or-none modular grammatical deficit championed by the RDDR.

The linguistic accounts of SLI have provided detailed descriptions of the grammatical deficits of SLI, particularly in English. And here lies the nub of the problem with most of these accounts: even if they perfectly captured the SLI phenotype in English, the findings are not grammatically consistent across languages.

Cross-linguistic evidence

In Italian, all nouns, verbs, and adjectives are inflected. Nouns are inflected for number (singular, plural) and gender (feminine, masculine). Adjectives must agree with the nouns they modify in number and gender; similarly articles, which can be definite or indefinite, must agree with the noun they precede in terms of number and gender. Verbs are inflected for tense, person, and number. All inflections are word-final and syllabic, and are usually weak syllables following a strong syllable (since most words are stressed on the penultimate syllable). Pronominal clitics are used in a range of grammatical functions, express person and number, but cannot stand alone (unlike full pronouns).

In the field of morphosyntax, Italian-speaking children with SLI seem to have disproportionate difficulty with function words such as articles and clitics. In analyses of spontaneous speech samples, the percentage of use of these two types of morphemes in obligatory contexts was significantly lower in a group of children with SLI than in younger children with similar mean lengths of utterance (Cipriani et al., 1991; Leonard et al., 1992). These morphemes also posed difficulty for children with

SLI, relative to MLU controls, in a comprehension task. The level of omission of articles for the Italian children with SLI was comparable to that of a group of English-speaking children with similar MLU (Leonard et al.).

In contrast to their difficulty with function words, and unlike their English-speaking counterparts, Italian-speaking children with SLI do not appear to have particular difficulty with grammatical inflections. Percentage use of adjective agreement inflections, noun plural inflections, and verbal inflections, though less frequent than that of age controls, was similar to that of MLU controls (Leonard et al, 1992; Bortolini and Leonard, 1996). The only exception was the relatively frequent substitution of the 3rd person plural verb inflection with the 3rd person singular inflection (while 1st and 2nd person inflections, both singular and plural, were generally used correctly). The robustness of grammatical inflections in these children also held in the context of comprehension tasks (Leonard et al, 1992). It is interesting that children with SLI were unlikely to use the infinitive form in finite contexts (Bottari, Cipriani, and Chilosi, 1995), as might be predicted by the Extended Optional Infinitive account. Finally, direct comparison between Italian and English-speaking children with SLI revealed that the Italian children were significantly more likely to use the 3rd person singular verb inflection, and more likely (though not at a statistically significant level) to use the noun plural inflection (Leonard et al, 1992; Bortolini, Leonard, and Caselli, 1998).

Spanish and Italian typology are very similar, and a recent study by Bedore and Leonard (2001) compared the findings reported in Italian to the use of grammatical morphology in Mexican Spanish-speaking children with SLI. Using grammatical probes, they found that, as in Italian, use of verb inflections was relatively robust, with the children with SLI similar to MLU-controls both qualitatively and quantitatively. Problems were concentrated in noun-related morphemes such as adjective-agreement inflections (not found in Italian) and direct-object clitics. Perhaps surprisingly, both direct and indirect articles were relatively spared. In terms of the types of errors, substitutions were more common than the omissions usually reported in other languages; the substituted form tended to share most of the target's features (e.g. there might be an error in number, but correct marking of tense and person). A finding relating to the noun plural is particularly interesting with respect to some of the differences between Italian and English: like English, and unlike Italian, Spanish has a number of nouns which require the consonantal *-s* to mark the plural. Spanish-speaking children with SLI were less likely than their MLU controls to use this allomorph, and it is possible that in Spanish and English it is the consonantal *-s* which poses difficulty, while the vocalic plural allomorph in Italian is easier.

The profile of grammatical morphology in children with SLI has also been extensively studied in Hebrew, which is an inflectionally rich language that is typologically very different to Romance and Germanic languages in the form of its inflections. All verbs and many nouns and adjectives consist of a consonantal root which conveys the basic meaning plus a pattern, or binyan, which modulates the meaning by expressing notions such as reflexivity and causality. For example, the root *l-v/b-sh* means *wear/dress.* Pronounced in the context of Binyan 1, it becomes *lovesh* meaning *he wears [e.g. a hat].* In Binyan 5, it becomes *mitlabesh* meaning *he dresses himself*" (example taken from Owen, Dromi, and Leonard, 2001).

Studies by Rom and Leonard (1990) and Dromi, Leonard and Shteiman (1993) found that Hebrew-speaking children with SLI were no worse than MLU controls on adjectival agreement and noun plural morphology. They did have deficits with the accusative case marker *et*, and a less clear cut deficit with the definite prefix *ha-*. With respect to verb morphology, although children with SLI resemble MLU controls in their use of the present tense, they fall behind in the use of the past tense. Dromi, Leonard, Adam and Zadunaisky-Ehrlich (1999) attributed this to the more complex nature of the past-tense agreement paradigm in Hebrew, in which number, gender and person must all be marked, in contrast to number and gender marking only in the present tense. The errors children made with these verbs was reminiscent of the Spanish data described above, in that many substitutions were 'near misses', differing from the target form in only one feature. In a further study, Leonard, Dromi, Adam and Zadunaisky-Ehrlich (2000) examined the possibility that the difficulty with the past-tense was in fact a difficulty with past-tense per se rather than the complex agreement paradigm. While the task used in the Dromi et al. (1999) study required children to select agreement but not tense, the task in Leonard et al. (2000) required selection of the appropriate tense. In this situation, the children with SLI exhibited difficulty with one particular binyan, both in present and past forms; in all other binyanim, in both present and past forms, they performed as well as MLU controls. The authors concluded that the difficulty could not be due to the nature of the past tense itself. Some of the errors observed in the verb morphology of Hebrew-speaking children with SLI have been attributed to deletion of weak initial and medial syllables, or substitution of initial consonant segments with a glottal stop, both of which may well result in an incorrect binyan (Dromi et al., 1993; Owen et al., 2001).

In general, cross-linguistic evidence from Italian, Spanish and Hebrew suggests that these language pose far fewer problems in inflectional morphology for children with SLI, than does English. The areas of difficulty vary across languages, with the Romance languages apparently leaving verb morphology relatively intact, while in Hebrew the past tense in particular can be problematic, possibly due to its highly complex agreement paradigm.

It is clear that the same grammatical deficit cannot account for the linguistic profile seen in SLI across different languages. This is a serious problem for accounts which posit a deficit in universal grammatical structures. For example, verb inflections are an important part of the I-system presumed missing in the functional category deficit account, and are also an integral part of the Extended Optional Infinitive and missing agreement hypotheses. The finding that they are not particularly affected in Italian-speaking children with SLI is problematic for all these accounts.

The surface hypothesis

If the language profiles described in SLI cannot be attributed to universal linguistic deficits, the explanation must lie at a more basic, non-linguistic level. In his surface hypothesis, which is an example of a general processing deficit account, Leonard (1998) proposes that the factors which can identify the weak structures in each language lie not at a deep, representational and grammatical level, but at the surface of language. Factors such as frequency, phonological redundancy and perceptual salience are specific to the typology of a language, but are not linguistic as such. For instance, agreement markers are less perceptually salient in English than in Italian: in English they are brief and unstressed relative to adjacent morphemes, while in Italian they are syllabic and of similar length to adjacent morphemes. The Surface Hypothesis suggests that when a system is stressed (for example, by a hypothesised reduced speed of processing in SLI), vulnerable elements such as English inflections will be dropped. More robust elements, such as Italian inflections, will survive.

Cross-linguistic evidence suggests that language problems could be attributable to pre-linguistic deficits. This then begs the question of just how pre-linguistic the deficits might be. At its most basic level speech is an acoustic signal which must be perceived by the listener's auditory perceptual mechanisms; at least in the early stages of perception speech is presumably processed by the same mechanisms that process non-verbal auditory stimuli. What would be the effect on language development if something at this basic auditory level were to go wrong?

Auditory processing in SLI: the groundwork

Much of the early work on auditory processing deficits was done by Tallal and colleagues, starting with a study in which it was shown that children with SLI needed ten times as much time between two differently pitched tones in order to be able to tell that they were different (Tallal & Piercy, 1973a, 1973b). Participants (6-9 year old children with SLI and age-matched controls) were trained to associate Tone 1 with one button and Tone 2 with another. They then had to listen to different combinations of these tones (1-1, 1-2, 2-1, 2-2) and press the buttons in the corresponding order. The tone duration was always 75 ms, but the inter-stimulus interval (ISI) was randomly varied between 8 ms and 4062 ms. When the ISI was 428 ms or longer, there was no difference in performance between the SLI group and their matched controls. However, with shorter ISI's the performance of the SLI group deteriorated dramatically. While control children were well over the 75% correct threshold at 8 ms ISI, children with SLI needed over 300 ms ISI to reach a similar level of performance. A similar pattern of results was found when a same-different rather than a sequential ordering paradigm was used with the same subjects.

The main (and well-known) conclusion of this study was that children with SLI have a temporal processing impairment, which means that they cannot integrate sensory information which impinges on the nervous system in rapid succession. Speech, which by its nature comprises rapidly changing sequences of auditory information, is thus very vulnerable.

A secondary finding from this study was that stimulus duration also plays a role in performance. The tones in the discrimination/sequencing task were 75 msec. At this tone duration, when subjects were asked to sequence a three-element series, the SLI group was significantly worse than the controls. When the tone duration was increased to 250 msec, there was no difference in performance. The performance of the SLI group could thus be characterised as showing a deficit in processing either brief or rapid stimuli.

It should be noted that even at the longer duration of 250 ms, if the sequence was increased to five elements SLI children were again at a disadvantage; suggesting that a memory/sequencing problem lies over and above the discrimination of brief or rapid stimuli.

In the initial Tallal and Piercy (1973b) study, in addition to the auditory task, children were given two coloured patches (different shades of green) which they had to discriminate and sequence. The performance of the SLI children was indistinguishable from that of the control children on this task. However, in a more extensive study (Tallal, Stark, Kallman & Mellits, 1981) it was found that younger children with SLI performed poorly on both the auditory and visual tasks, while the older children with SLI performed poorly only on the auditory task, suggesting an age-effect. The visual stimuli in this study were letter-like forms, while the auditory stimuli were the tones used by Tallal and Piercy, (1973a, 1973b) as well as /b▶/ and /d▶/ synthesised speech sounds. Rapid processing in the tactile modality was also tested, based on discrimination of single, sequential, or simultaneous touches to the fingers. Fine-grained motor production was examined with respect to nonverbal finger and mouth movements, as well as rapid production of single or sequential speech syllables and words. In all these cases it was found that children with SLI were impaired in comparison to controls in their ability to:

> discriminate, sequence, or remember any brief stimulus if followed in rapid succession (tens of milliseconds) by another stimulus, regardless of the modality of stimulation. (Tallal, Miller & Fitch, 1993, p. 33)

Tallal's hypothesis regarding the processing of brief or rapid stimuli in the auditory domain leads to specific predictions about which types of speech stimuli should be harder for children with SLI to process. The first 40-50 ms of stop consonants contain the information by which the consonants are differentiated (e.g. voice onset time); these should therefore be difficult to tell apart. Vowels, in contrast, have their critical information more evenly spread over time; these should be easy to tell apart. This prediction was borne out (Tallal & Piercy, 1974; Tallal, Stark & Curtiss, 1976) and /b►/ and /g►/ were harder for children with SLI to tell apart than vowels. However, the difference in difficulty could also be attributed to the formant transition in consonants contrasted to the 'steady-stateness' of vowels (in a formant transition intensity changes with frequency, whereas in steady-state it does not). Truncating the vowels and stretching the formant transitions resulted in loss of the vowel advantage, so the formant transition per se does not appear to be the cause of the difficulty (Tallal & Piercy, 1975). In a later study (Tallal & Stark, 1981), it was shown that children with SLI also did poorly on discriminating /s►/ and /► ►/, which differ on spectral rather than temporal cues, while they had little difficulty with vowels of only 40 ms duration (/◄I/ vs. /►/). The conclusion drawn was that brief steady-state stimuli are difficult to discriminate only if they are followed very quickly by another sound. Leonard, McGregor and Allen (1992) found similar results:

children with SLI had difficulty with stop consonants /b/ and /d/ and fricatives /s►/ and /► ►/, but not with vowels, except where these were followed rapidly (within 35 ms) by another sound.

The age-effect mentioned earlier appears to also come into play in phoneme discrimination: when 29 of the children from the Tallal et al. (1981) study were retested, 24 reached criterion on the /b►/-/d►/ contrast, whereas four years earlier only 10 managed to discriminate reliably between the two consonants (Bernstein & Stark, 1985). It is clear that the performance of the same individuals improved significantly with age. Evidence for age-effects in psychophysical tasks has also been reported by Jensen & Neff (1993): it was found that with regard to frequency and duration discrimination there was a marked improvement with age between 4 and 6 years, and that even at 6 years there was a large discrepancy between child and adult performance. Intensity discrimination did not appear to be so reliant on age.

Measures of auditory temporal processing in SLI and developmental dyslexia

Following the initial reports of Tallal and colleagues there have been a number of studies seeking to replicate and expand their findings. One interesting development has been that the idea of a central auditory processing deficit as a primary cause of language impairment, although developed initially in SLI, has for the last two decades been taken up with some enthusiasm by dyslexia researchers. The logical chain of causation follows the same pattern for both SLI and developmental dyslexia: an early deficit in processing brief or rapid sounds leads to less fine-grained speech discrimination; this impaired phonological processing then gives rise to the broader language difficulties found in both disorders. An important point of divergence is that while the link between phonological processing and language impairment is controversial in the SLI literature, the causal link between a phonological deficit and reading impairment is almost universally accepted (Liberman & Shankweiler, 1985; Mann, 1984; Stanovich, 1986, 1988; Vellutino & Scanlon, 1987, Bradley & Bryant, 1978, 1983). Nonetheless, at the level of the auditory deficit and its associated speech perception and phonological deficits, there has been a large amount of cross-talk between the SLI and dyslexia fields, with the implicit (though not necessarily justified) assumption that findings and conclusions in the one disorder also apply in the other.

In a thorough review of the literature pertaining to a temporal processing deficit in developmental dyslexia, Farmer and Klein (1995) outlined a sequence of perceptual and cognitive steps that are necessary precursors to successful performance on a temporal order judgement task, such as the one used by Tallal and colleagues. Firstly, individual stimuli must be detected, and pairs of stimuli must be individuated, so that there is a percept of two (or more) separate stimuli. Secondly, stimuli must be identified in terms of a dimension such as intensity, frequency, or duration. Identification is necessary for discrimination of the stimuli as being different with respect to the relevant dimension; a temporal order judgement can then be made about the two stimuli. A final level of complexity is introduced when a series of more than two stimuli is presented, as this adds a significant memory load to the perceptual requirements of the task (although note that deciding the order of two stimuli still requires remembering which came first and which came second).

Virtually none of the studies reviewed by Farmer and Klein (1995) found a stimulus detection deficit in dyslexia, whereas a large number found a stimulus individuation deficit (in both auditory and visual domains). The focus, however, is on the large number of studies which have reported a deficit in temporal order judgement tasks. Tallal (1980) employed the same paradigm used in earlier studies in SLI, and found that like children with SLI, children with developmental dyslexia were impaired on temporal order judgements for high-low tones at short ISIs. Performance on this task correlated strongly (.81) with a non-word reading task (which is considered to be a test of phonological awareness), as well as with other reading measures. Using a very similar task with children with dyslexia, Reed (1989) found impaired temporal order judgement for pairs of pure tones at short ISIs, as well as for pairs of stop consonant-vowel syllables. Pairs of vowels, in contrast, were not problematic even at short ISIs, which is the pattern that would be predicted on a temporal processing deficit account. The same pattern of performance held when the task required only same/different discrimination rather than temporal order judgement, for both Tallal (1980) and Reed (1989). De Weirdt (1988), in a study of 9-year old children with dyslexia as well as 6-year old pre-reading children who went on to become poor readers, reported similar findings of impaired same/different discrimination for both pure tones differing in frequency and consonant-vowel syllables. A deficit in temporal order judgement has also been reported in adults with dyslexia, in both the auditory and visual modalities, although the auditory stimuli here were clicks rather than pure tones (Kinsbourne, Rufo, Gamzu, Palmer, and Berliner, 1991).

Not all the evidence has been positive, however. In a large-scale longitudinal study carried out by Share and colleagues (Share, Jorm, MacLean & Matthews, 2002), an unselected sample of over 500 children was assessed at school entry on Tallal's temporal order judgement task (often referred to as the auditory repetition test, or ART). Three years later the children were classified as specific reading disabled (discrepancy between reading ability and IQ), general reading backward (no discrepancy between reading ability and IQ), or normal readers. Although the specific reading disabled (referred to in this study as RD) group were impaired on the auditory repetition test at school entry, their weakness was with long ISIs rather than the expected short ISIs. Further, in terms of severity of impairment in phonology and reading measures, RD children who had performed poorly on the ART were no different to RD children who had performed well on the ART. The converse pattern was also found, namely that a subgroup of children who had performed poorly on the ART went on to develop normal phonological and reading skills. Finally, although there was a reliable correlation between performance on the ART and phonological skills at school entry, ART performance did not predict later phonological impairment. It is difficult to square these findings with the claim that the phonological deficit seen in developmental dyslexia is subsumed by a non-linguistic auditory temporal processing deficit, at least as far as this is indexed by the ART. However, it is noteworthy that Share and colleagues did find that early performance on the ART predicted later reading comprehension weaknesses and oral receptive vocabulary, which could be supportive of an auditory temporal processing deficit in SLI if not dyslexia. This raises the interesting possibility that if an auditory temporal processing deficit has a role to play in SLI, it may not be via the expected and obvious route of a phonological deficit.

The version of the temporal processing deficit hypothesis put forward by Tallal and her colleagues critically depends on a disproportionate difficulty with items that are presented in rapid succession, that is, with rate. The lack, or rather reversal, of the expected rate effect in the Share et al. (2002) study is therefore a serious problem for this hypothesis. The critical rate effect is also absent in a study comparing performance on a task very similar to the ART in groups of adolescents and young adults with SLI and autism (Lincoln, Dickstein, Courchesne, Elmasian &

Tallal, 1992). Although the SLI group had the overall poorest performance, and all groups (SLI, autistic, and control) were less accurate with faster rates of presentation, this did not interact with group. The dimension of the task that did separate the SLI group from the other groups was the number of stimuli in the sequence, leading the authors to conclude that a short-term auditory memory deficit rather than a rate deficit was most prominent in the SLI group. It is possible, however, that a rate deficit may have been present earlier in life, but had resolved by adolescence. Such an age-effect cannot explain the findings of Share et al., 2002, who were testing children in the earliest school-years. Nor can it explain the findings of Nittrouer (1999) who administered a version of the auditory repetition task to 8- to 10- year old children and found no interaction of group (group membership determined by phonological skills) with rate of presentation.

Besides the question of *when* a rate deficit might be apparent, there is also the question of *whom* it affects. Most researchers agree that dyslexia, and perhaps even more so SLI, are very heterogeneous disorders in which one would not expect to find a unitary cause which can explain the range of difficulties to be found within each clinical group. Nonetheless, relatively few studies explicitly consider the sub-groups which comprise most experimental groups. Early on, Tallal (1980) reported that in a group of children with developmental dyslexia, only those who showed concomitant oral language difficulties performed more poorly than controls in the temporal order judgement task; moreover, only those children who performed poorly on the temporal order judgement task had phonological difficulties as assessed by a nonword reading task.

More recently, Heath, Hogben & Clark (1999) explicitly compared, the performance of disabled readers with concomitant oral language delay (LDRD) and disabled readers with normal oral language (SRD) on an auditory temporal order judgement task and phonological decoding (nonword reading task). Only the group with concomitant oral language delay showed a deficit in the temporal order judgement task, while the 'pure' reading disabled group was indistinguishable from the age-matched normal reading group. Thus far the results replicated those of Tallal (1980). However, even within each of the two reading disabled groups there appeared to be a bimodal distribution, with only 5 of the 11 children in the LDRD group performing poorly while the remaining 6 were within the range of the control readers. Further, when the SRD group was subdivided into groups of high- and low-language-ability based on post-hoc examination of their scores on the oral language subtests (rather than the overall oral language score used for initial screening purposes), it transpired that there were significant differences in performance on the temporal order judgement task. Finally, there was no transparent relationship between phonological decoding skill and temporal order judgement ability; the correlation between the two measures was weak, and it was not the case that children with normal temporal order judgement were 'spared' phonological difficulties. This pattern of results strongly suggests that an auditory temporal processing deficit is present in only a subgroup of children who have both oral language and reading difficulties, and that the relationship with phonological deficits is far from straightforward.

Temporal order judgement tasks have clearly yielded mixed results in the question of a 'temporal processing deficit' in language impairment and dyslexia. However, they are not the only type of task which can be used to investigate auditory temporal processing, and it is possible that there is a deficit just waiting to be found by the right sort of probe. A relatively recent candidate is the backward masking paradigm, which yielded exciting results in a study by Wright et al. (1997).

Participants (8 children with SLI and 8 age- and IQ-matched controls) were presented with a brief tone (20 msec) before, during, or after a masking noise. Control children found it hardest to detect the tone when it was presented during the noise, easier when it immediately followed the noise, and easiest when it immediately preceded the noise. In contrast, children with SLI, apart from needing a higher tone level in all conditions, found it very difficult to detect the tone when it immediately preceded the masker. The difference was so dramatic that there was no overlap in performance between the two groups. This would indeed seem to be evidence for the idea that for children with SLI, when one stimulus follows closely on another, it interferes with the perception of that stimulus because the central auditory system has not had sufficient time to process it.

Similar findings in dyslexia were reported by Rosen and Manganari (2001), who found significantly higher thresholds for backward masking in a group of teenagers with dyslexia than in controls. However, there were no differences between the groups on forward and simultaneous masking.

Less clear-cut results were obtained in a recent study involving children with SLI and poor reading skills, children with SLI and average reading skills, children with specific reading disability and average oral language skills, as well as control children with normal reading and oral language skills (McArthur & Hogben, 2001). A different version of the backward masking task was used here, based on the auditory backward recognition masking (ABRM) task developed by Massaro and Burke (1991). Children were presented with two clusters of three tones each: the first tone in each cluster was the standard tone which had the same intensity in all clusters and all trials, the second tone was the test tone whose intensity was variable across trials (in one or the other cluster), and the third tone was a masking sound which followed the second tone after a variable ISI. The child's task was to determine which cluster of tones contained the less intense test tone; an estimate was then obtained of the lowest intensity at which the child could reliably identify the target cluster. In a finding reminiscent of Heath et al. (1999), McArthur and Hogben (2001) found that only a sub-group of children who had both oral language and reading difficulties were impaired on the auditory backward masking task. Performance on the auditory task did not relate to any of the language measures administered. The authors also emphasised the finding that a subgroup of children with either SLI or specific reading disability performed poorly on a simple intensity discrimination task, and suggest that a discrimination deficit could confound the results from more complex tasks which do not actively control for auditory discrimination ability.

One of the few studies to look at more than one index of central auditory processing in the same individuals was reported by Bishop, Carlyon, Deeks & Bishop (1999). The importance of carrying out such within-subject comparisons was recently highlighted by Heath and Hogben (2001), who found extremely low intercorrelation between scores on the ART and the ABRM task used by McArthur and Hogben (2001), for the same group of children with developmental dyslexia.

Bishop et al. (1999) estimated thresholds for detecting backward masked tones, frequency modulation, and pitch discrimination using temporal cues. Performance on these measures was also compared with performance on the ART carried out two years previously: a reliable relationship was found, suggesting that the measures were tapping into the same auditory process, which remained stable over time in a subset of the children tested. However, none of the measures were able to discriminate between children with SLI and controls. It is interesting to note that performance was influenced more by nonverbal than verbal ability, and that in terms of absolute performance it was not so much that the language-impaired group had low thresholds but that the control group had high thresholds. The authors discuss the possibility that the cognitive demands of psychophysical tasks may contribute to auditory thresholds, thus masking 'pure perception' in low IQ controls. A similar masking of 'pure perception' has been discussed in the context of attentional factors in SLI; that is, because many children with SLI have poor attention, it is difficult to be certain that their responses in a psychophysical task reflect perception rather than attention!

Auditory temporal processing and speech perception

An important issue which arises in any experiment addressing the question of an auditory temporal processing deficit in language impairment is how a deficit in the perception of non-speech stimuli relates to speech perception: this relationship is absolutely necessary to any hypothesis attempting to attribute language difficulties to a low-level perceptual deficit. A number of researchers have described difficulties in speech perception, in both SLI and developmental dyslexia. The difficulty seems to arise particularly with regard to stop consonants, but more broadly with any phoneme which is rapidly followed by another sound (Tallal & Piercy, 1974,1975; Tallal et al., 1976; Tallal & Stark, 1981; Reed, 1989; De Weirdt, 1988; Leonard, McGregor & Allen, 1992). The underlying assumption is that changes in the speech-stream follow one another rapidly in time in a similar way to that in which non-speech stimuli (usually tones) follow one another in a temporal order judgment or backward masking task, thus neatly linking speech and non-speech perception.

Studdert-Kennedy and Mody (1995) raise a vehement challenge to this assumption. They argue that the speech-stream (unlike the written alphabet) is not sequential in nature, and that information about successive elements is carried in parallel rather than serially. The phenomenon of coarticulation means that perception of the word 'cat' does not simply require the concatenation of /k/, /►/, and /t/ sounds, because the /►/ carries information both about the preceding /k/ (perseveration) and about the following /t/ (anticipation). Similarly, the formant transitions at the start of a stop consonant-vowel syllable carry information both about the consonant and the subsequent vowel. Therefore one cannot draw a simplistic parallel between the perception of 'cat' and the perception of a sequence of discrete tones, no matter how quickly these follow one another. Furthermore, the formant transitions of different consonants differ in the direction and loci of their frequency changes; these are spectral differences rather than temporal ones, particularly for synthetic stimuli where the duration and rate of frequency change (unarguably temporal properties) are held constant.

Rather than tone sequences, an arguably more appropriate non-speech analogue of speech discrimination tasks might involve stimuli which have the same duration and frequency trajectories as the formant transitions in CV syllables, but which are not heard as speech. Mody, Studdert-Kennedy and Brady (1997) presented a discrimination and temporal order judgement task to a group of poor readers, and found (as expected) that they were more impaired on /b►/-/d►/ contrast than on a /b►/-/s►/ or /d►/-/► ►/ contrast, when the ISI was short. Mody and colleagues posed the question that if, as it appeared, /b►/ and /d►/ are difficult to discriminate because they are similar, is their similarity phonetic or acoustic? The same subjects were presented with sine waves that had the same duration and frequency trajectories as the second and third formants that carry the /b►/-/d►/ contrast: this time, the poor readers had no difficulty with the contrast, even at short ISIs. Mody et al. concluded that any deficit present in these poor readers must be phonetic (that is, specific to language) and not a general deficit in rate of auditory processing.

Going one step further, Sussman (1993) cast doubt on the presence of even a phonetic deficit per se in 5- to 6-year old children with language impairments. In a discrimination task which required them to detect a change from /b►/ to /d►/, children with language impairment performed as well as younger language-matched controls. The CV syllables were synthesised such that the only differences between them were located in the second and third formant transitions. Children with language impairment can therefore be described as having normal sensitivity to these formant transitions, in direct contradiction of the predictions of the auditory temporal processing deficit account. In contrast, when the task required children to identify and categorise a syllable as being a /b►/ or a /d►/, children with language impairment were at a significant disadvantage, leading Sussman to conclude that the deficit lay not in perception, but in identification and categorisation of phonetic stimuli.

Going even further, Nittrouer (1999) reported that children with poor phonological skills were no worse than children with normal phonological skills on a task which required them to use the information carried in formant transitions in order to make a phonetic categorisation decision for CV syllables. For instance, in a decision involving a token of /s►/ which had to be categorised as either /s►/ or /► ►/, the vocalic portion could contain either a formant transition appropriate for either /s/ or /► / (temporal cue), and an initial fricative noise from a continuum ranging from /s/ to /► / (spectral cue). Children with poor phonological skills tended to make their categorisation based on the appropriate formant transition, even if this meant overriding the spectral cue from the fricative noise (i.e. if the /►/ contained a formant transition appropriate for a /s/ the children would categorise the syllable as /s►/ even if the initial portion was actually closer to /▶ /). The brief, temporal information carried in the formant transitions was clearly not problematic for the children with poor phonology; their weakness was, if anything, in utilising spectral information. This pattern of results parallels that seen in younger children who are developing language normally (Nittrouer, 1992, 1996). It is not the first time that difficulties with fricatives have been reported in language impairment, and the argument has been that it is not the fricative itself that is problematic, but the fact that in any CV syllable the initial sound is followed rapidly by another phoneme (Tallal & Stark, 1981; Leonard et al, 1992). In any case, any version of the auditory temporal processing deficit account must predict difficulty with formant transitions regardless of other elements of the speech signal that might prove problematic. The paradigm used by Nittrouer (1999) was successful in isolating the use of formant transitions, and the evidence that the use of these is robust in children with poor phonological skills casts serious doubts on how well a deficit in auditory temporal processing can account for speech perception deficits.

In an interesting prediction about how speech perception might relate to non-verbal auditory processing as indexed by backward masking, and reminiscent of the study by Leonard, McGregor and Allen (1992), Rosen and Manganari (2001) suggested that perception of /b▶/ versus /d▶/ should be poorer in dyslexia than /▶b/ versus /▶d/. The reasoning is that in /b▶/ and /d▶/, the supposedly critical formant transition is followed by a vowel in the same way that the target tone is followed by the masking tone in backward masking; for individuals with poor backward masking thresholds, therefore, these syllables should be hard to discriminate. On the other hand, in /▶b/ and /▶d/ the formant transition follows the vowel, and a parallel can be drawn with forward masking, which appears to be robust in individuals with SLI and dyslexia. However, despite finding poor backward masking and normal forward masking performance in a group of teenagers with dyslexia, the authors reported that there were no differences between perception of /b▶/-/d▶/ and /▶b/-/▶d/, other than that the control group was better overall than the dyslexic group. Further, in isolation (i.e. a non-speech context), perception of the same second formant used in the CV syllables was nearly as good in the dyslexic group as in the control group. Rosen and Manganari (2001) concluded that while there did appear to be an auditory processing deficit in their teenagers with dyslexia, it:

> cannot... be simply characterized as a difficulty in processing rapid auditory information. Either there is a linguistic/phonological component to the speech perception deficit, or there is an important effect of acoustic complexity (p. 720).

It is worth considering that if a requirement of acoustic complexity is shown to be necessary to sustain the argument for an auditory temporal processing deficit, the distinction between speech and non-speech perception may become meaningless.

Quite a different approach to examining the relationship between auditory processing and phonology was taken by Bishop, Bishop, Bright, James, Delaney and Tallal (1999). In a twin study comparing performance on Tallal's auditory repetition test (ART) and the Children's Nonword Repetition Test (CNRep, Gathercole & Baddeley, 1996), it was found that the two abilities have different origins. While performance on CNRep has high heritability, performance on the ART does not, suggesting that phonological deficits may not be simply secondary consequences of an auditory processing impairment (although nonword repetition is not a purely perceptual task). However, even if auditory deficits are considered an environmental rather than genetic factor, it is still possible that they exert an adverse influence on language development if they are present during critical language-learning periods. For instance, in this study poor auditory processing as indexed by ART exerted an independent influence on performance on a test of grammatical comprehension (TROG). This finding is reminiscent of Share et al. (2002), who found that early performance on the ART was predictive of later oral receptive vocabulary. However, it is unclear by what mechanism auditory temporal processing can impact on language development if it is not via phonology.

Summary

The language profile of children with language impairment is complex and varies across individuals and over the course of development. Extensive studies, many of them based on the paradigm of generative grammar, have provided detailed descriptions of this language profile, with a particular emphasis in the field of inflectional morphology, and largely if not exclusively in English. However, the aim of any truly explanatory account must be to seek out how the impaired pattern of language development emerges from psychologically and physiologically plausible processes. The accumulated evidence to date seems to support the hypothesis of an auditory temporal processing deficit, in at least some individuals with SLI and/or dyslexia. The precise nature of this deficit and how it relates to impaired language development is as yet an unresolved issue, and calls for further exploration.

Chapter 2: Coherent Motion Sensitivity in SLI

Introduction

SLI and developmental dyslexia have traditionally been regarded as distinct conditions, but it is increasingly argued that they may be part of the same language-development continuum. It is striking that much of the research in both fields is concerned with 'temporal information processing' (ill-defined though that term might often be). Additionally, children with SLI often have co-occurring literacy problems, and children with dyslexia sometimes show oral language deficits. A recent study which examined the reading and oral language scores of 102 children with SLI and 110 children with dyslexia found that more than half of the children in each group could equally be classified as dyslexic or SLI (McArthur, Hogben, Edwards, Heath & Mengler, 2000). Furthermore, the language profiles of pre-school children who go on to be diagnosed as dyslexic often include oral language deficits (Scarborough, 1990). In a pair of studies comparing children identified as having either language impairment or reading impairment, Kamhi and colleagues found that the two groups were indistinguishable on measures of phonological awareness, such as phoneme deletion and segmentation (Kamhi & Catts, 1986; Kamhi, Catts, Mauer, Apel & Gentry, 1988). Finally, a prospective study of children who were at genetic risk of dyslexia (at least one first-degree relative with dyslexia) found that 57% of the at-risk children had literacy delay at age 6, compared to only 12% in a control sample. The children with literacy delay could be distinguished from those with normal literacy at age 6 on the basis of oral language measures, including phonological tasks, administered three years previously (Gallagher, Frith & Snowling, 2000).

The extent of the overlap between literacy and language disorders is dramatic. However, the question of whether the disorders are qualitatively or only quantitatively different is as yet unresolved. If the difference is quantitative, and SLI and dyslexia arise from a similar underlying disorder, a paradigm which taps into this mechanism and shows a deficit in one disorder should also reveal a deficit in the other. The hypothesis tested by the following three experiments presented in this thesis is that children with SLI will show deficits in processing visual and auditory dynamic stimuli of the type that have been found to be problematic in developmental dyslexia, as predicted by the 'magnocellular hypothesis' for dyslexia.

The 'magnocellular hypothesis' for dyslexia posits a deficit in the systems that process the dynamic (i.e. changing over time) aspects of stimuli, across sensory and motor domains. It is hypothesised that these dynamic-processing systems are rooted in cerebellar timing mechanisms: in support of this is the frequently reported clinical observation that developmental dyslexics are often clumsy and have poor fine motor co-ordination (well-established roles for the cerebellum). The experimental evidence that many children with dyslexia also have poor balance, particularly when a secondary task is introduced, has been interpreted as a deficit in task automaticity, which is traditionally associated with the cerebellum (Nicolson & Fawcett, 1990, 1995).

The broader predictions of the 'magnocellular hypothesis' are that individuals with dyslexia should exhibit difficulties with processing dynamic stimuli in any sensory domain, and there is supporting evidence for this prediction from the tactile domain (Stoodley, Talcott, Carter, Witton & Stein, 2000), and more extensively the auditory domain (McAnally & Stein, 1996, 1997; Witton et al., 1998). However, the original impetus for the 'magnocellular hypothesis' came from vision research, as reflected in the name, and by far the most extensive research in this paradigm has been in the visual domain. There is now accumulated neuroanatomical, neuroimaging, and psychophysical evidence to support the idea that individuals with developmental dyslexia have impaired functioning of the magnocellular visual pathway.

The M and P visual pathways

The human visual system has two basic pathways, which process motion and form/colour information independently. These pathways have both subcortical and cortical manifestations; subcortically the anatomical segregation between the two is much clearer than it is cortically. The axons of M-type and P-type retinal ganglion cells target the magnocellular and parvocellular layers of the lateral geniculate nucleus (LGN) respectively. From here they project to primary visual cortex (V1), with magnocell axons terminating in layers 4B and 4Cα, and parvocell axons in layer 4Cβ. After this the anatomical and functional separation becomes less distinct; nonetheless, the M-pathway forms the main input to the dorsal visual stream which projects to parietal areas, while the P-pathway (as well as some M input) feeds the ventral stream which terminates in the temporal lobes. The dorsal stream is associated with the perception of motion and the location of objects in space (giving it the nickname of the "where" stream), while the ventral stream is associated with the analysis of form and colour (the "what" stream).

The different functions of the M and P-pathways reflect the differences in the temporal and spatial properties of M- and P-type cells. Magnocells have large cell bodies and thickly myelinated axons which allow them high transfer velocities: this means they are well equipped to encode information about the onset and offset of transient stimuli, and their responses tend to be transient. Parvocells are smaller and are slower conductors; they tend to fire continuously for the duration of a stimulus, in a sustained response. A second important difference between the two types of cell is the size of their receptive fields. Magnocells have large receptive fields which pool information from a large number of photoreceptors: this makes them good at detecting the coarse features of stimuli, at low spatial frequencies, and low luminance. Parvocells by contrast, have small receptive fields with input from a smaller number of cells, and are therefore sensitive to the fine-grained features of stimuli, at high spatial frequencies. As a result of these differences, the M-pathway is maximally responsive to stimuli with low spatial and high temporal frequencies, while the P-pathway analyses stimuli with high spatial and low temporal frequencies. This corresponds to the separate processing of form and motion.

The association of the M-pathway with the perception of motion at both cortical and subcortical levels has been amply demonstrated experimentally. In macaques (whose visual system is similar enough to that of humans to be useful as a model), lesions of the mLGN, but not pLGN, result in motion-blind scotoma (Schiller, Logothetis & Charles, 1990); they also result in reduced luminance contrast sensitivity for stimuli of high temporal frequency and low spatial frequency, which are the conditions the M-stream operates best in (Merigan & Maunsell, 1990). Cortically, one of the major targets for the M-stream is MT (V5) and lesions of this area in humans result in a selective inability to perceive movement, while colour perception and visual acuity are spared (Zihl et al, 1983). In the macaque, single unit recordings of cells in MT can accurately reflect behavioural decisions in a coherent motion detection task. Even more impressively, stimulation of single cells in MT can affect the behavioural response (Britten et al, 1992).

Anatomical and functional evidence for a magnocellular deficit in dyslexia

The most direct evidence for a magnocellular deficit in dyslexia comes from a post-mortem study on the brains of 5 individuals who had been diagnosed with developmental dyslexia in life, compared to 5 control brains (Livingstone, Rosen, Drislane & Galaburda, 1991). In the magnocellular layers of the LGN of the dyslexic brains, the cells were significantly smaller (by 27%) and more disorganised than in the control brains. In contrast, there were no group differences in the P-layers of the LGN.

Anatomical abnormalities have also been observed cortically, in the primary visual cortex (V1): while control brains were found to have larger neurons in the left hemisphere, there was no hemispheric asymmetry in the dyslexic brains (Jenner, Rosen & Galaburda, 1999), although these abnormalities did not correspond directly to input from the magnocellular layers of the LGN. A lack of leftward asymmetry (and sometimes even a rightward asymmetry) has also often been reported in the planum temporale (PT) of individuals with dyslexia; however, as PT is an auditory association area, it is not directly relevant to a discussion of the visual magnocellular pathway. In fact, a group of dyslexics who had a documented magnocellular deficit (according to a psychophysical task) were found to have normal leftward asymmetry of the PT (Best & Demb, 1999). There is also biochemical evidence which indicates a lower density of large neurons in the left temporo-parietal cortex of adults with developmental dyslexia; this would be consistent with reduced magnocellular input to the posterior parietal cortex (Rae et al., 1998).

Unsurprisingly, the anatomical abnormalities of dyslexic brains have functional repercussions. Visual Evoked Potential (VEP) responses, which are believed to tap V1 function, showed that when adults with dyslexia were presented with checkerboard patterns whose luminance contrast was reversed at either high or low frequencies, they had a different pattern of responses to control subjects. When the stimuli had low contrast and rapid reversals (15 Hz), which are characteristics favourable to M-pathway function, the dyslexics had slow and highly attenuated VEPs. In contrast, they had normal responses to high-contrast, slowly reversing stimuli, which would processed by the P-pathway (Livingstone et al., 1991). These findings have recently been replicated in a group of teenagers with dyslexia: VEPs were smaller in the dyslexic group for rapidly reversing but not slowly reversing checkerboard patterns (Romani et al., 2001).

There is also fMRI evidence for a motion-processing deficit at cortical levels. Using a speed discrimination paradigm (measuring the minimal increase in stimulus speed which is just noticeable), Demb, Boynton and Heeger (1998) reported reduced brain activity for dyslexics in V1 as well as MT. They also found strong three-way correlations between brain activity, speed discrimination thresholds, and reading speed. MT was also implicated in an fMRI study by Eden et al. (1996) found that while V5/MT was strongly activated in controls when they were presented with moving stimuli, it was virtually inactive in dyslexics. By contrast, presentation of stationary patterns resulted in the same activation patterns for both dyslexics and controls.

Psychophysical evidence for a magnocellular deficit in dyslexia

A number of different visual psychophysical paradigms have been used to tap M-system (transient) function, and most of them take advantage of the well-known characteristics of this system: a preference for low spatial and high temporal frequency, and its inhibitory action on the P-system (sustained).

One such task measures visible persistence, and alternates presentation of a stimulus pattern (e.g. a sinewave grating) with a blank field matched in average luminance: the ISI is varied until the subject sees a clear blank, and this interval is taken as the measure of the duration of visible persistence. The underlying mechanism is assumed to be the interaction between the sustained and transient systems, so that a short duration of persistence is due to strong inhibition by the transient system on the action of the sustained system. It follows that duration of persistence should increase if the transient system is less active, for example at high spatial frequencies. This is what is observed in controls, but in children with dyslexia there is relatively little increase in the duration of visible persistence at high spatial frequencies, which suggests a weak transient system (Badcock & Lovegrove, 1981; Slaghuis & Lovegrove, 1985). One way to conceptualise this is in terms of a floor effect: if the transient system isn't doing much in optimal circumstances (low spatial frequencies), it doesn't have space to get much worse when the going gets harder (high spatial frequencies). Another way to reduce transient system activity is to introduce a secondary stimulus, such as a flickering grating, which will 'distract' the transient system. In normals, introducing a flickering grating into a visible persistence task results in increased persistence duration (Breitmeyer, 1981); in children with dyslexia, it does not (Slaghuis & Lovegrove, 1984).

Contrast sensitivity, measured in terms of the contrast in luminance between the pattern and background of a stimulus, also appears to be poor in children with dyslexia at low but not high spatial frequencies (Martin & Lovegrove, 1984). As before, introducing a flickering grating to the task reduces contrast sensitivity in controls, but not dyslexics (Martin & Lovegrove, 1987). These findings are consistent with the visible persistence findings, and support the idea of a transient system deficit in dyslexia.

Instead of using a flickering grating as a masking stimulus, Martin and Lovegrove (1987) also examined sensitivity to flicker directly. They found that while children with dyslexia had lower flicker sensitivity than controls overall, the group differences were greatest at high temporal frequencies (20 and 25 Hz), as would be predicted for a weak transient system.

In contrast to the results from visible persistence, contrast sensitivity, and flicker sensitivity experiments, Lovegrove and colleagues found no deficits in their dyslexic groups in tasks that tapped sustained rather than transient system function. For example, there were no group differences in sensitivity to the orientation of lines, or to the spatial frequency of sinewave gratings (reported in Lovegrove, Martin & Slaghuis, 1986). The conclusion drawn from this work was that there is a selective deficit in the functioning of the transient visual system in developmental dyslexia.

An important issue that emerges from such a conclusion concerns the nature of the mechanism relating a visual perceptual deficit to the reading difficulties associated with dyslexia. One possibility, favoured by Lovegrove and colleagues (Lovegrove et al., 1986), arises from the prolonged visible persistence caused by weak transient-on-sustained inhibition. Eye movements during reading involve 200 ms foveal fixations during which information from the printed page is seen, interleaved with saccades which bring the next segment of text into foveal vision for analysis. If the sustained response for each fixation lasts beyond the saccade and into the next fixation, it will interfere with the processing of the novel information by acting as a forward mask. In normal reading, the transient system responds briefly to each stimulus onset and offset, and thus inhibits the sustained response at the fixation boundaries, preventing visual confusion. If the transient system is compromised, this inhibitory function is weakened, and reading difficulties ensue (Breitmeyer, 1980). It should be noted that a critical assumption underpinning this model is that the transient system suppresses the sustained system during saccadic eye movements: this assumption has recently been challenged by Skottun and Parke (1999), who argue that it is the transient and not the sustained system which is suppressed during saccades.

It seems less likely that the reduced luminance contrast sensitivity or the low flicker sensitivity found in dyslexia have any direct impact on reading development: the studies which reported reduced contrast and flicker sensitivity obtained their measurements in low luminance conditions (the so-called mesopic range, at less than 10 cd/m^2 - candelas per square meter). However, most human activities, including reading, take place in brightly lit conditions (photopic range of above 40 cd/m^2). When contrast and flicker sensitivity were measured under photopic conditions, children with dyslexia were indistinguishable in their performance from controls (Cornelissen, Richardson, Mason, Fowler & Stein, 1995).

A large number of studies have examined contrast sensitivity in dyslexia, and the majority of these have reported differences between dyslexic and control groups. However, only a few have shown reduced sensitivity in dyslexia for both low and medium frequency stimuli; this could be interpreted as providing only equivocal support for a magnocellular deficit (for review see Skottun, 2000).

Coherent motion sensitivity in dyslexia

Most of the visual psychophysics tasks discussed so far have gauged transient system function by using stimuli, such as sinewave gratings, which could be processed by either the transient or sustained pathways. However, in these tasks the stimulus conditions are made optimal for the transient system, almost as though luring the magnocells in to do the job. A more direct way to measure transient system activity is to use a stimulus which can only be processed by the M-pathway. Such a stimulus is a random dot kinematogram (RDK), in which a certain proportion of the dots in the display move in a coherent fashion while the rest move randomly.

Coherent motion sensitivity is defined in terms of the smallest proportion of dots which must be moving in a given direction for movement in that direction to be perceived by the viewer.

Recently, a large number of studies have successfully applied the RDK paradigm to the investigation of visual deficits in dyslexia. In comparisons of individuals with dyslexia (both adults and children) controls, a number of studies have found significantly higher coherent motion thresholds in the dyslexic group (Talcott et al., 1998; Talcott, Hansen, Assoku & Stein, 2000; Hansen, Stein, Orde, Winter & Talcott, 2001; Witton et al., 1998; Pammer & Wheatley, 2001).

An important observation that emerges from one of the earlier studies to find a coherent motion deficit in dyslexia (Cornelissen et al., 1995) is that while the groups are clearly different in their overall performance, there is nonetheless a large degree of overlap; there is also high within-group variability, particularly within the dyslexic group. A similar pattern of results was found when adults with dyslexia were compared to normally developing children with an equivalent reading age: this is a conservative matching design, which controls for the possibility that reading experience itself may contribute in a top-down way to a processing deficit. Nonetheless, significant group differences were found again, despite overlap and within-group variability in performance.

This variability and overlap may go some way towards accounting for the negative findings that have been reported in the literature. A recent study carried out by Ramus and colleagues (Ramus, Rosen, Dakin & Frith, 2001), reported that the dyslexic groups in their samples were as proficient as the control groups at detecting coherent motion. However, the weight of the evidence suggests that at least some individuals with developmental dyslexia exhibit a motion processing deficit.

The precise underlying mechanism of the deficit remains unknown, but a recent proposal is that individuals with dyslexia have fewer motion detectors than normal readers. In a study which selectively manipulated dot duration and dot density in an RDK display, the performance of the dyslexic group improved significantly with increased dot density, but not increased duration. This suggests that the difficulty does not lie in perceiving brief visual stimuli, but in perceiving a signal embedded in noise. Although increasing the overall dot density did not alter the signal-to-noise ratio, it did increase the absolute number of target dots moving in one direction, allowing the increased motion signal to accumulate in cells (presumably in MT) tuned for that direction of motion (Talcott et al., 2000).

Whatever the mechanisms underlying the deficit in coherent motion detection, it does seem to be specific to the M-pathway, consistent with the predictions of the magnocellular hypothesis. Regardless of whether or not they find evidence in favour of a magnocellular deficit, virtually none of the studies examining visual deficits in dyslexia have reported evidence of a parvocellular deficit, which might be reflected in something like reduced visual acuity or colour perception (cf. Amitay & Ahissar, 2001).

With respect to coherent motion perception in particular, the most direct P-pathway analogue is coherent form perception; this requires the detection of a static shape embedded in a random background, rather than movement (see Figure 2.1 for an illustration). Coherent form tasks have been found to give psychophysical thresholds that are independent of motion coherence in typical adults (Braddick, 1998). Form and motion coherence detection have also been found to activate distinct brain areas, with no differentiation in V1 but very clear separation in subsequent extrastriate visual cortex. Interestingly, both tasks activated areas in both parietal (usually associated with M-function only) and temporal (associated with P-function) cortex: although the areas of activation remained distinct and thus indicated a clear functional separation, this did not follow the expected anatomical separation of dorsal and ventral pathways (Braddick, O'Brien, Wattam-Bell, Atkinson & Turner, 2000). Based on these findings, an individual with a selective magnocellular deficit should have reduced sensitivity to motion coherence but normal sensitivity to form coherence. This pattern of performance was recently confirmed in a group of adults with dyslexia: significantly higher coherent motion thresholds were coupled with normal thresholds on two form coherence tasks. In one of the form coherence tasks, the target was in a fixed position, while in the second the position of the target was randomised; the dyslexic group exhibited slightly (but not significantly) increased thresholds with the randomised target position task, which the authors attribute to the visual search element introduced in this task (Hansen et al., 2001).

The search for a psychophysical marker of a reading or language disorder is partly motivated by a desire to uncover the underlying mechanisms of the disorder, but also because it would be a useful tool for identifying young children with dyslexia or SLI before they actually exhibit the language deficits. This is based on the understanding that the earlier a problem is caught, the more effective the remediation can be. To this end it is important to ascertain how well a marker can discriminate between those individuals with a disorder and those without. One early attempt to do this was carried out by Slaghuis & Lovegrove (1985), who were able to classify 75% of their group of children with dyslexia correctly based on a transient visual system deficit. More recently, Talcott et al. (1998) were able to discriminate 72% of adults with dyslexia from controls based on a combined measure of coherent motion and flicker sensitivity. However, it is worth noting that these figures would give poor sensitivity for screening purposes, as the relatively low incidence of dyslexia in the general population (approximately 10%) would have to be taken into account.

Rationale for the current study

The weight of the evidence suggests that a large proportion of individuals with developmental dyslexia exhibit a magnocellular deficit, extensively demonstrated in reduced sensitivity to moving stimuli. If developmental dyslexia and SLI are indeed different manifestations of the same underlying dynamic-processing problem, as is increasingly assumed in the literature, reduced motion sensitivity should be demonstrable in children with SLI. The current study, therefore, is an examination of motion sensitivity in a group of children with SLI.

The hypothesis tested by the current study was that children with typical SLI would show reduced sensitivity to a coherent motion stimulus, relative to their peers. However, they were predicted to have normal sensitivity to a coherent form stimulus: form perception is a function of the parvocellular visual pathway, which is hypothesised to remain unaffected in language impairment.

In addition to the group of children with SLI, a small group of children identified as pragmatically language impaired (PLI) were also examined on these tasks. At the time of testing, the Children's Communication Checklist was under development (Bishop, 1998) as a tool for identifying children with potential PLI, and distinguishing them from children with SLI whose difficulties are primarily with the structure of language. It was thought that including children with PLI in a psychophysical study might give some initial insight into whether they share the perceptual deficits reported in children with SLI .

Method

Participants

Criteria for inclusion in the SLI group were nonverbal ability within the normal range, and performance worse than one standard deviation below the mean on two out of four of the following tests of linguistic ability, and a CCC score greater than 132. All the tests described below provide age-standardised norms, with a mean score of 100 and standard deviation of 15.

BPVS: British Picture Vocabulary Scale (Dunn, Dunn, Whetton & Pintilie, 1982). A measure of receptive vocabulary. The child has to choose a single picture from a choice of four to match the word read out by the experimenter. Difficulty increases throughout the test, and testing stops when the child gets four wrong out of a consecutive series of six.

TROG: Test for the Reception of Grammar (Bishop, 1989). A measure of receptive syntactic ability. The child chooses one out of four pictures to match the sentence read aloud by the experimenter. Sentences increase in syntactic complexity throughout the test, and testing stops only at the last item.

CELF-R: Recalling Sentences subtest of the CELF (Clinical Evaluation of Language Fundamentals, Semel, Wiig & Secord, 1987). A measure of expressive language and verbal memory. This test requires the child to repeat verbatim a list of sentences read out by the experimenter. Responses are scored on-line according to the number of errors made, with a score of 4 for a perfectly accurate repetition, and a score of 0 for four or more errors in a single sentence. Sentences increase in length and complexity throughout the test, and testing stops following four consecutive '0' scores.

CNRep: Children's Test of Nonword Repetition (Gathercole & Baddeley, 1996). A measure of phonological short-term memory, in which the child repeats a list of 40 nonsense words. The nonwords are pre-recorded and presented either on a tape recorder or computer, and increase in length from one syllable at the beginning of the test to five syllables at the end.

Nonverbal ability was assessed using Raven's Coloured Progressive Matrices (Raven, Court & Raven, 1986). In this test the child has to choose which of six choices will best complete the given pattern; these become progressively more difficult throughout the 36 item test, but each child is required to attempt all items on the test.

Eleven children identified as SLI according to the criteria outlined above were recruited from Language Resource Bases in Oxfordshire state schools. The age range at time of testing was from 6:11 (years: months) to 12:5, with a mean of 9:10.

In addition to the children with SLI, four children who met the criteria for SLI but who also scored highly (above 132) on the Children's Communication Checklist (Bishop, 1998) were included as a PLI (Pragmatic Language Impairment) group.

Children for the control groups were recruited from mainstream classes in a different Oxfordshire state primary school. A group of 12 children was matched to the SLI group on the basis of age (± 3 months) and nonverbal ability (standardised Raven's scores ± 5). A further four children were selected on the same basis as a control group for the PLI group. All children in the control groups performed within normal limits on three of the four language measures outlined above (BPVS, CELF-R, CNRep).

All children who participated in this study had returned signed parental consent forms. According to parental report, all children were monolingual in

English, and none of the children had suffered from permanent hearing loss. None of the children in the control groups had any history of speech or language difficulties.

Table 2.1 provides means and standard deviations for the ages and Raven's matrices scores of the groups, as these were the criteria on which groups were matched.

Mean (SD) *min - max*	**SLI** ***n* = 11**	**PLI** ***n* = 4**	**SLI-Control** ***n* = 12**	**PLI-Control** ***n* = 4**
Age **(years:months)**	9:10 (1:10) 6:11 - 12:5	8:10 (0:11) 7:6 - 9:4	10:0 (1:9) 7:3 - 12:5	8:10 (0:9) 7:9 - 9:4
Raven's Matrices	101.82 (11.16) 86 - 125	115.50 (9.15) 103 - 125	100 (8.08) 88 - 114	119.75 (6.08) 114 - 125

Table 2.1: Group profiles, for the matching criteria of age and nonverbal ability.

Stimuli and Procedure

Motion coherence

A Random Dot Kinematogram stimulus was presented in a two-alternative forced-choice task. Children were presented with two patches of moving dots on the computer screen (11" TFT monitor, Gateway 2000 Solo), one of which showed left-right directional motion, the other of which showed Brownian motion. Children were asked to point to the patch containing coherent motion, and were encouraged to guess if they were uncertain. The proportion of dots moving in the same direction varied in a 1-up 1-down fashion, according to a Kaernbach staircase procedure (Kaernbach, 1991). Correct responses were followed by a decrease in the coherent motion signal at a constant ratio of 1 dB; errors were followed by an increase in the signal of 3 dB. Testing stopped at 10 reversals, and a threshold was obtained by averaging the values of the last 8 reversals.

Patch size for the motion task was 300 pixels (height) by 200 pixels (width), subtending approximately 9° X 11° of visual angle at a viewing distance of approximately 60 cm. A 50 pixel gap (2°) separated the two patches. Screen refresh rate was set at 16.5 msec or 60.7 Hz. There were 150 high luminance (131 cd/m^2) dots per patch, each dot one pixel in size (subtending 0.05° X 0.09°), on the black background of the monitor display. In order to prevent the possibility of the observer following the trajectory of a single dot, each dot had a fixed lifetime of 5 animation frames (82.5 ms). Reversal time for the direction of motion (left or right) was 20 frames (330 ms), and total display time for each trial was 50 frames (825 ms). Initial coherence level (i.e. proportion of dots in the target panel moving in the same direction) was 50%.

Form coherence

Two patches were again presented to the child, this time with short lines of random orientations. In one of the patches a proportion of the lines were oriented in the same direction to form a circle; the salience of the circle decreased as the proportion of lines of the same orientation decreased. Once again, the child pointed to the panel where she or he saw the circle. The adaptive staircase was the same as that used for the motion detection task (Kaernbach, 1991), and thresholds were estimated in the same way.

Patch size for this task was again 300 pixels (width) by 200 pixels (height), with a horizontal separation of 60 pixels; as before, screen refresh rate was at 16.5 msec or 60.7 Hz. There were 600 line segments per panel, each of these 8 pixels long. Circle radius was 80 pixels, and initial coherence was set at 75%. The main difference from the motion detection task in terms of task design, was that while for motion the display was limited to under one second, display time in the form detection task was unlimited. The stimuli remained on the screen until the experimenter pressed the computer key corresponding to the child's response. This decision was made because, at least with adult observers, performance on the motion task becomes asymptotic past a certain display time and does not improve significantly with unlimited display time (Talcott et al., 2000). This is not known to be the case for form detection.

The position of the target patch (left or right side of the screen) was randomised in both motion and form coherence tasks. Six thresholds (three for each task) were obtained in a single testing session, which typically lasted 20-30 minutes. Order of task presentation was counterbalanced across subjects.

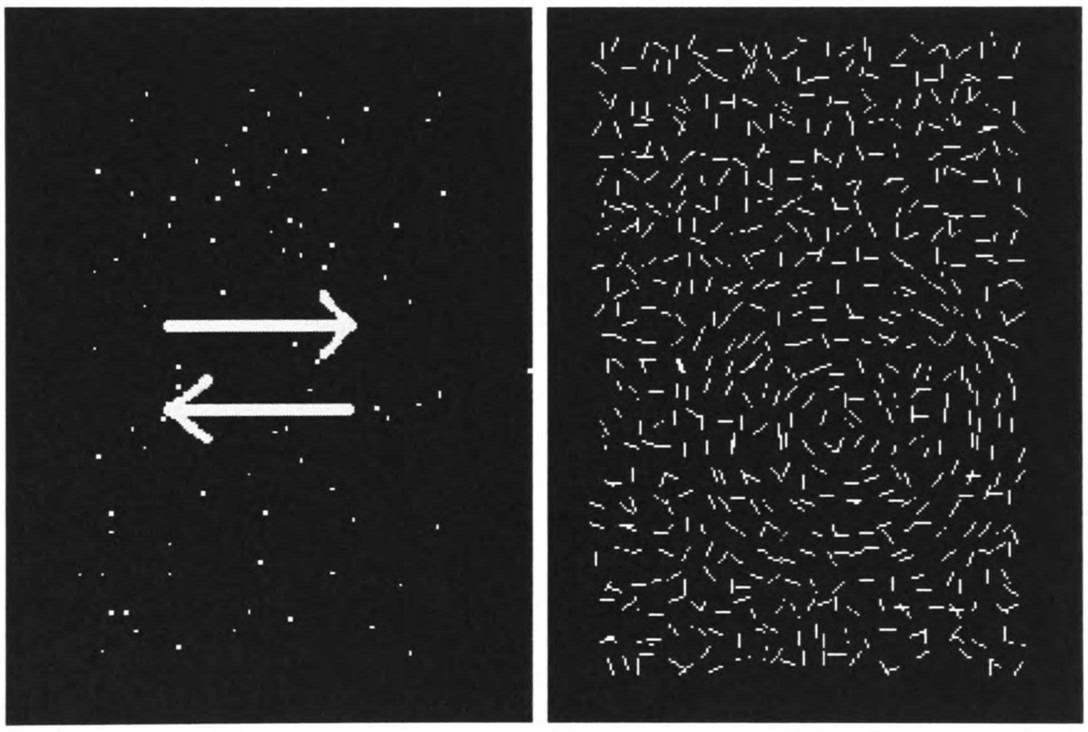


Figure 2.1: Examples of stimuli used for motion coherence (left) and form coherence (right). The arrows have been added for illustrative purposes, and indicate direction of motion.

Results

The experimental hypothesis predicted that children with language impairment would obtain significantly higher thresholds than typically developing children in the motion coherence task but not the form coherence task. Such a finding would support the view that SLI and developmental dyslexia share an underlying deficit, and that part of that deficit is reduced sensitivity to visual motion.

Measure of performance

Three threshold estimates were obtained for each child, for each task. The first of the three (identical) runs from which the thresholds were obtained was considered a practice run. The question arose as to whether the 'practice threshold' should be included in the overall measure of performance, or whether only the last two estimates should be included.

Inspection of the data revealed that, particularly in the case of motion coherence, there seemed to be a noticeable improvement in performance (i.e. lower thresholds) between the first and second threshold estimates, but not between the second and third estimates (Figure 2.2). Note that the data from one extreme outlier in the motion coherence task (subject PLI-4) is not included in any of the graphs or subsequent statistical analyses involving motion detection thresholds. With the exclusion of this data, the distributions for all motion and form coherence thresholds did not differ significantly from normality, according to 1-sample Kolgorov-Smirnov tests.

Additionally, in all the statistical analyses that follow (in this and subsequent experiments) degrees of freedom have been adjusted for inhomogeneity of variance where necessary.

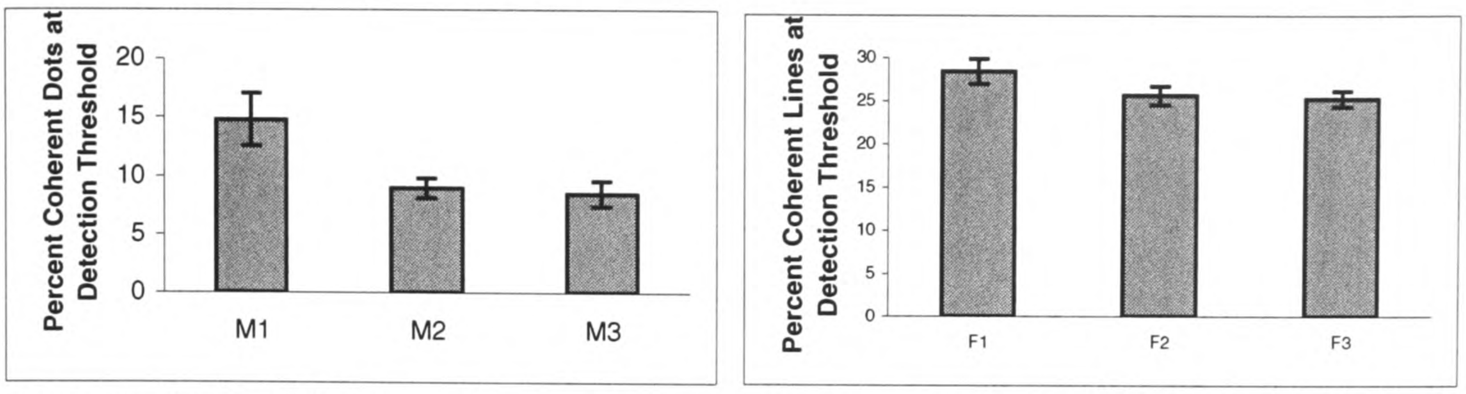


Figure 2.2: Means of first, second & third coherent motion (left) and form (right) detection thresholds (motion, n = 30; form, n = 31).

In the case of coherent motion, the pattern of a significantly different first threshold estimate was statistically confirmed. A repeated-measures analysis of variance showed that there was a significant main effect of threshold [F (2,60) = 7.23, p < .01]. Paired samples t-tests clarified that Threshold 1 was significantly higher than Threshold 2 [t (29) = 3.03, p < .01] but that Thresholds 2 and 3 were not significantly different from each other [t (29) = 0.76, p > .05]. This pattern of performance did not vary between groups: the threshold x group interaction was non-significant [F (6, 54) = 0.65, p > .05].

The same pattern was not found for coherent form: the repeated-measures ANOVA showed a non-significant main effect of threshold [F (2, 60) = 2.33, p > .05] as well as a non-significant threshold x group interaction [F (6, 54) = 1.29, p > .05].

Finally, paired samples t-tests showed that the average of all three thresholds and the average of the last two thresholds were significantly different in the case of motion coherence [t (29) = 3.34, p < .01], and approached significance in the case of form coherence [t (30) = 1.85, p = .07].

In light of these differences, it appears that considering the first run to be a practice run is justified, and that the threshold estimate obtained from this run should not be included in the final measure of performance. In subsequent graphs and analyses, the reported threshold for both motion and form coherence detection will be the average of the second and third threshold estimates.

Group comparisons

Figure 2.3 shows group thresholds for motion coherence detection; there did not appear to be significant differences in motion detection thresholds between the SLI and SLI control groups. There also did not appear to be a significant difference between the PLI and the PLI control group. This is contrary to the prediction of the experimental hypothesis.

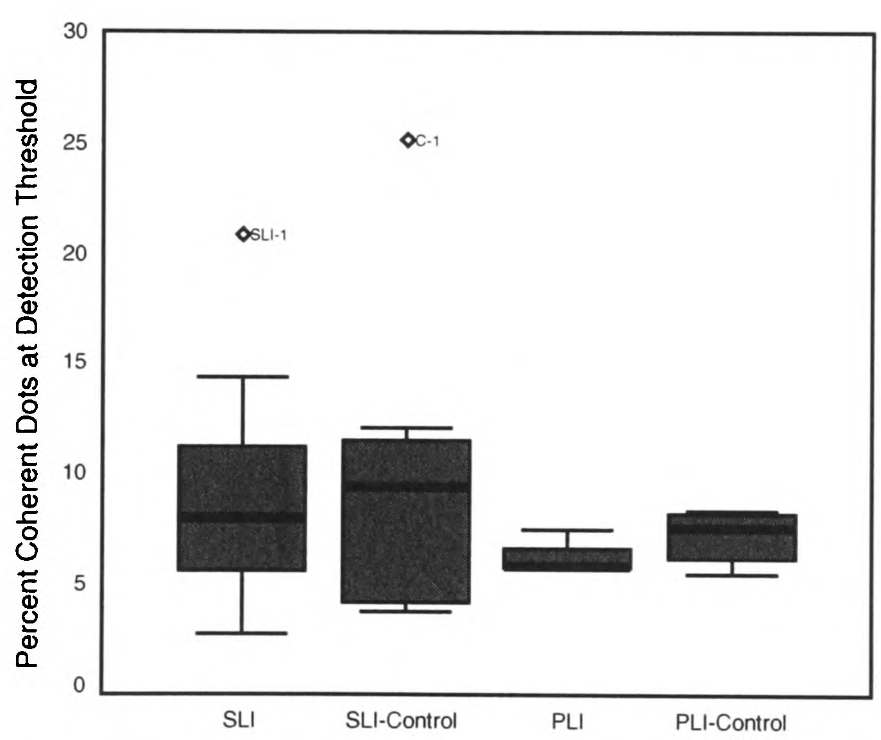


Figure 2.3: Coherent motion detection thresholds. Boxplots indicate the median, quartiles and extremes of the distribution.

An independent-samples t-test confirmed that the means of the SLI and SLI control groups were not significantly different (Table 2.2).

Group	*n*	*Mean*	*SD*	*t*	*df*	*p*
SLI	11	9.06	5.24	-.18	21	.86
SLI-Control	12	9.48	5.95			

Table 2.2: Coherent motion detection means for SLI and SLI-Control groups, and independent-samples *t*-test.

The PLI and PLI control groups are too small to merit statistical analysis, but it seems fairly clear that there were no significant group differences. Note, however, that the single extreme outlier in all the subjects tested (whose motion detection threshold of 63.09 was excluded from graphs and analyses) came from the PLI group.

There were also no significant group differences in performance on coherent form detection; Figure 2.4 clearly illustrates that coherent form detection thresholds were very similar across the four groups. This is in line with the prediction of the experimental hypothesis.

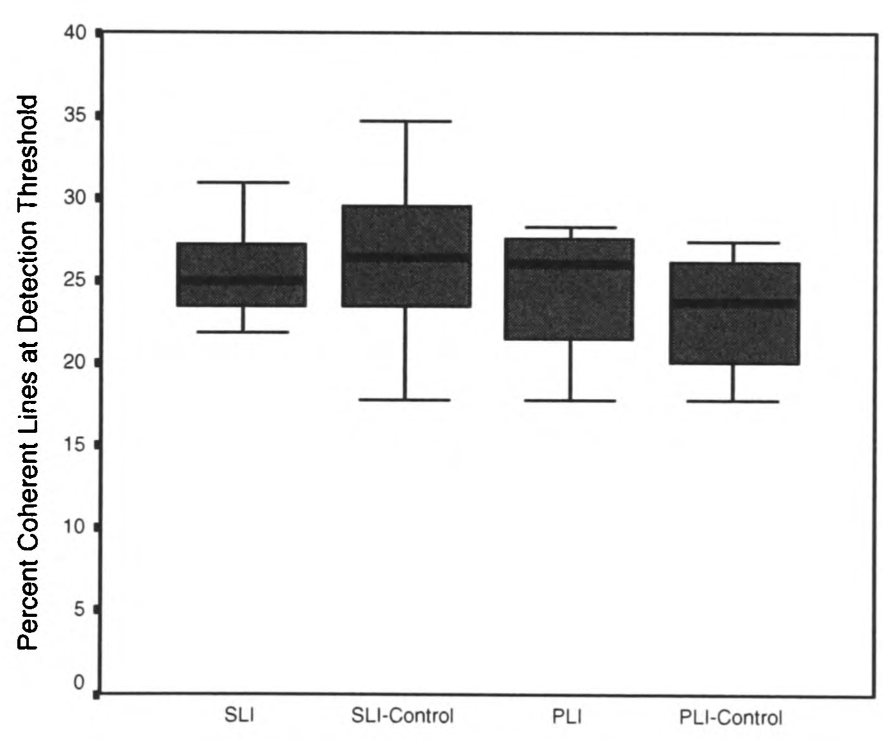


Figure 2.4: Coherent form detection thresholds. Boxplots indicate the median, quartiles and extremes of the distribution.

An independent samples t-test confirmed that there were no group differences in form coherence detection thresholds between the SLI group and the SLI-Control group (Table 2.3).

Group	***n***	***Mean***	***SD***	***t***	***df***	***p***
SLI	11	25.54	2.91	-.53	21	.60
SLI-Controls	12	26.44	4.93			

Table 2.3: Coherent form detection threshold means for SLI and SLI-Control groups, and independent-samples *t*-test.

Again, though the PLI group is too small to merit statistical analysis, there did not appear to be a difference in performance from the PLI Control group.

It is interesting to note that variability in performance was greater in the coherent motion than in the coherent form task, clearly visible in the box-plots and reflected in the standard deviations from the means. This may be because in the form coherence task, the stimulus patches were on the screen indefinitely, that is, until the response button was pressed; while in the motion coherence task the panels were on the screen for less than one second (for reasons discussed earlier). This may have made the motion task more difficult, and the range of performance more variable; however, it should be noted that all children tested were able to do the motion task with confidence and apparent ease. Alternatively, it may be that there is greater variability for detecting motion than for detecting form inherent in the human visual system. In any case, the amount of variability in performance does not appear to differ between the language-impaired and control groups.

'Perceptual learning'

It is clear that there were no between-group differences in mean detection thresholds for either motion or form coherence tasks. Nor did there seem to be a difference in within-group variability between language-impaired and control groups. A remaining possibility is that a mild perceptual deficit might reveal itself in a slower rate of improvement between threshold estimates rather than in an absolute increase in detection thresholds. In this case it might be expected that the language-impaired groups will show a smaller difference between Threshold 1 and Thresholds 2 and 3 than the control groups. A measure of percentage change between the 'practice' and 'experimental' runs was therefore calculated for both motion and form coherence tasks. Independent samples t-tests revealed no group differences for either motion [*t*

(21) = 0.26, $p > .05$] or form [t (21) = 1.02, $p > .05$] coherence sensitivity. Insofar as this measure corresponds to some form of 'perceptual learning', it is clear that children with language impairment show no disadvantage. However, the correlation between average threshold and 'perceptual learning' was negligible for the motion coherence task [r (29) = .06, $p > .05$], although not for the form coherence task [r (30) = -.62, $p < .001$], suggesting that it is not a particularly reliable measure.

Order of task presentation

It is possible that task practice effects or fatigue may have influenced performance on one task more than another. However, independent samples t-tests showed that order of presentation made no difference to mean thresholds for either motion coherence detection [t (28) = 0.24, $p >.05$] or form coherence detection [t (29) = -0.10, $p > .05$].

Age effects

Age correlated strongly with motion detection thresholds [r (29) = -.48, $p < .01$], suggesting that performance improves with age. This effect can be clearly seen within the control groups [r (15) = -.62, $p < .05$], and holds slightly less strongly within the language-impaired groups [r (13) = -.39, $p > .05$]. The correlation between form coherence detection thresholds and age was negligible [r (30) = -.08, $p > .05$].

Control task

Form coherence has not been much used as a control task for motion coherence tasks, so it is important to review its suitability for the role. Performance on the coherent motion and coherent form detection tasks was highly *unrelated* [r (29) = .12, $p > .05$), so to this extent the coherent form task is a good control. However, the inter-correlations between thresholds for this task were surprisingly low: F1:F2 [r (30) = -.12, $p > .05$], F2:F3 [r (30) = .14, $p > .05$], F1:F3 [r (30) = .25, $p > .05$]. This is in stark contrast to the situation for motion coherence detection thresholds, where the inter-correlations between the three threshold estimates were highly significant: M1:M2 [r (29) = .53, $p < .01$] M2:M3 [r (29) = .81, $p < .01$], M1:M3 [r (29) = .65, $p < .01$]. Motion coherence sensitivity estimates remained stable over the course of the three estimates within a single session, while form coherence sensitivity estimates appear to be highly unreliable. This finding casts some doubt on the suitability of form coherence as an appropriate control task for this type of study.

Discussion

This study did not find low sensitivity to coherent motion in children with SLI, and is thus not compatible with the hypothesis of a visual magnocellular deficit in SLI. To the extent that a visual magnocellular deficit characterises dyslexia, this finding suggests that SLI and developmental dyslexia do not share an underlying perceptual deficit.

Visual and auditory deficits may produce different outcomes

A possible explanation for the present findings involves the most obvious difference between SLI and dyslexia: SLI is an impairment of oral language, which is auditory in nature, while dyslexia is an impairment of written language, which is by definition visual. On this view, it is perhaps less surprising that children with an oral (or aural!) language impairment do not demonstrate a visual deficit. Perhaps oral language impairment is related to aural deficits, and written language impairment is related to visual deficits.

A dichotomy similar to this has been proposed within developmental dyslexia, which is often described in terms of two subtypes: phonological and surface dyslexia (Castles & Coltheart, 1993). The former is described in terms of poor grapheme-to-phoneme conversion, and results in difficulty reading regularly spelled words: novel- or non-word reading is an effective probe for locating this deficit, as nonwords cannot be recognised visually and must therefore be identified phonetically. Surface dyslexia is described in terms of poor visual pattern recognition, and results in difficulties reading irregularly spelled words (such as yacht).

Farmer & Klein (1995) suggested that auditory and visual temporal processing deficits may correspond to phonological and surface dyslexia, respectively. This proposition was tested directly by Pammer and MacGregor (1999) who identified groups of children who conformed to either the phonological or surface pattern of dyslexia, and tested them on an auditory temporal order judgement task and a coherent motion detection task. The experimental prediction was that children with phonological difficulties would display greater difficulty on the auditory task while children with surface/visual difficulties would have greater difficulty with the visual task. This prediction was not borne out by the data; instead, the degree of overall reading lag was closely related to performance on both auditory and visual tasks, which were themselves highly intercorrelated.

However, separate contributions of auditory and visual dynamic signal sensitivity to normal reading development were reported by Talcott et al. (2000). A group of unselected 10-year old children were administered a coherent motion detection task and an auditory frequency modulation (FM) detection task, tapping visual and auditory 'magnocellular' processing respectively. The children also completed measures of phonological skill (nonword and exception word reading, and spoonerisms) and orthographic skill (a pseudohomophone test, which requires discrimination of real words - *rain* - from orthographically distinct but phonologically identical nonwords - *rane*). After controlling for nonverbal IQ and overall reading ability, performance on the auditory FM task was able to explain 24% of the variance in phonological processing skills, while the visual coherent motion task accounted for 20% of the variance in orthographic skill. The results of this study strongly support the independent roles of auditory and visual dynamic processing in the development of normal reading ability, even if they do not consistently dissociate in dyslexia.

There are three suggested routes through which magnocellular function may contribute to reading - or magnocellular dysfunction may contribute to reading breakdown. The first is the well-established role of the magnocellular system in encoding object location (Mishkin, Ungerlieder & Macko, 1983; Milner & Goodale, 1995): identifying the correct spatial position of letters in a word is an important part of reading, and letter-position errors have been reported in dyslexia (Cornelissen, Hansen, Hutton, Evangelinou, & Stein, 1998). The second route relies on the role of the magnocellular system in allocating attention during visual search (Vidyasagar, 1998; Vidyasagar & Pammer, 1999): impaired visual search has been reported in dyslexia (Brannan & Williams, 1987; Vidyasagar & Pammer, 1999). The third route involves the role of the magnocellular system in the control of eye-movements, and would attribute reading problems to poor fixation stability or poor control of saccades (Breitmeyer, 1981; Stein & Walsh, 1997; however Bishop, 1979, offers a different view).

Whether or not any of the above mechanisms linking visual magnocellular function to reading are accepted as causal in dyslexia, it is clear that none of these visual problems can in any way account for the oral language difficulties seen in SLI. An obvious question which arises here is whether the children with SLI who participated in this study were good readers: if they were, the failure to find a visual magnocellular deficit would not be surprising if visual magnocellular deficits damage the development of reading skills, but not oral language skills. In fact, they were not good readers; this issue will be discussed further in chapters 3 and 4.

If there is a magnocellular deficit in SLI, it seems more likely to be found in the auditory domain, and possibly to underlie the frequently reported phonological problems. Similarly, if there is a causal overlap between SLI and dyslexia, it seems likely to be in the area of phonology (and very possibly restricted to the phonological dyslexic subtype). It may be more fruitful, therefore, to explore the processing of dynamic auditory rather than visual stimuli.

Chapter 3: Frequency Modulation Sensitivity in SLI at 2 & 240 Hz FM

Introduction

The frequency and amplitude of natural speech changes continually, at both fast rates (for example, in formant transitions) and slower rates (intonation patterns over the course of a sentence). The perception of amplitude and frequency modulation is therefore critical to an accurate analysis of the speech signal. This has been demonstrated most directly by Drullman and colleagues (Drullman, Fetsen & Plomp, 1994a, 1994b; Drullman, 1995), who showed that amplitude modulations at rates of between 4 and 16 Hz were not only necessary but also very nearly sufficient for accurate identification of consonants and sentence comprehension. When a speech sample was high-pass filtered so that all amplitude variations below 4 Hz were eliminated, speech intelligibility was unaffected; similarly, intelligibility remained intact when a low-pass filter was applied so that all amplitude variations above 16 Hz were cut off. In a similar vein, Remez, Rubin, Pisoni & Carrell (1981) demonstrated that preserving only the time-varying properties of the speech signal, in three-tone sinusoids that mimicked formant patterns, was sufficient to allow accurate perception of the linguistic message. It is possible that a deficit in accurate detection of amplitude and frequency modulation underlies some of the phonological problems described in SLI (see Figure 3.1 for an illustration of AM and FM).

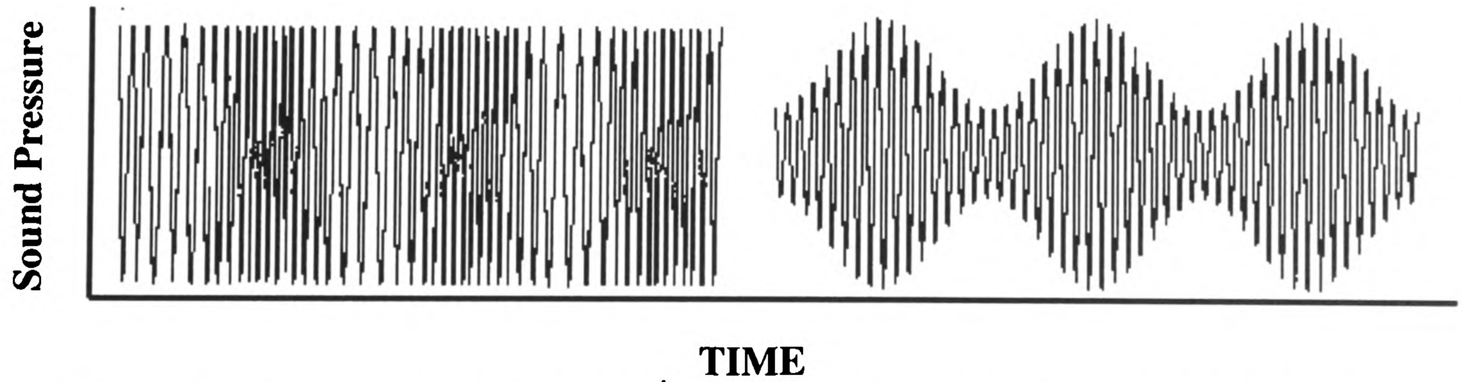


Figure 3.1: The left side of the diagram illustrates an FM - frequency modulated - wave, in which the frequency of the sound (in terms of cycles per second, or Hertz) changes over time. The right side of the diagram illustrates an AM - amplitude modulated - wave, in which the intensity of the sound (in terms of sound pressure) changes over time. Diagram adapted from Moore (1997).

Psychophysics of frequency modulation detection

An extensive series of psychophysical studies, initiated in the 1970's, provided evidence for the existence of specialised auditory channels for the analysis of frequency modulations (see Kay, 1982, for review). A conditioning paradigm was used to infer the existence of these channels: individuals who were exposed to a conditioning tone which was frequency-modulated were less sensitive to the modulations in a test tone (Kay & Matthews, 1972). The critical variable was the rate of modulation, so that the more similar the rate of modulation of the conditioning tone to that of the test tone, the lower the sensitivity to the modulation in the test tone. The greatest decrease in sensitivity occurred when the two modulation rates were equal, and particularly at low modulation frequencies there appeared to be fine tuning, so that the conditioning effects were reduced substantially once the conditioning rate moved away from the test rate by more than a few Hertz (Hz).

The specificity of the mechanism to the rate of frequency-modulation was emphasised by the finding that the actual carrier frequency of the conditioning tone was relatively unimportant: a 150 Hz or 350 Hz tone could interfere with modulation detection for a 250 Hz tone, as long as the modulation rate remained similar. Furthermore, amplitude-modulated tones, even ones with identical modulation rates and depths, were unable to influence the detectability of frequency-modulated tones, even though frequency-modulated tones could condition amplitude-modulated tones. Based on these findings, Kay and Matthews (1972) concluded that the human auditory system contains channels which are selectively tuned for particular frequency-modulations, and that their response is to the frequency-modulation itself and independent of the frequency of the carrier signal.

Neurophysiology of frequency modulation detection

The neural location of these specialised channels is probably in the higher levels of the auditory system. At the level of the auditory nerve, frequency information is encoded both temporally and spatially: for frequencies up to about 3.5 kHz, the nerve fibres can 'phase lock' or synchronise to the periodicity of the stimulus, firing in phase with the signal (Palmer & Russell, 1986). In addition, the basilar membrane of the cochlea in the inner ear is organised tonotopically, so that different locations on the membrane, and the corresponding afferent nerve fibres, are sensitive to different frequencies; the location of the responding receptor is therefore an indication of the frequency of the stimulus. Consequently, frequency or amplitude modulations of moderate rates will be directly reflected in the instantaneous firing rate of individual nerve fibres, and will be predictable from the nerve fibres' responses to steady tones.

The auditory nerve projects to the cochlear nucleus (ventral and dorsal) in the brainstem, which maintains tonotopic organisation. For the most part, the responses of neurones in the cochlear nucleus to modulated tones are consistent with their responses to steady tones. However, a minority of these neurones prefer particular directions of frequency modulation (upward or downward sweep) and are tuned for the rate of frequency change, with maximum sensitivity to rates of 10 - 30 Hz/s. The most effective modulating frequencies are in the range of 50 - 300 Hz (see Palmer, 1995, for brief review).

Projections from the cochlear nucleus target the superior olivary nuclei, which are concerned with interaural phase and intensity differences, and represent the early stages of binaural integration. From here, axons project to the lateral lemniscus and then to the inferior colliculus, which is where the first significant recoding of modulation information occurs. Rather than just being encoded in terms of which cells on the tonotopic map respond at which times, the mean discharge rate of groups of cells now reflects the modulations themselves; this indicates a first level of abstraction about modulation information (Rees & Palmer, 1989). Furthermore, the inferior colliculus is the first stage at which neurones with different 'best modulation frequencies' are distributed in a topographical map (Schreiner & Langner, 1988). Finally, the 'best modulation frequencies' for FM here are lower than those in the cochlear nucleus, and are below 80 Hz (Rees & Moller, 1983).

However, the clearest encoding so far observed for modulation information occurs in the primary auditory cortex, or A1. Projections from the inferior colliculus go through the medial geniculate nucleus of the thalamus, to A1 in the superior temporal gyrus. Here, a number of neurones were shown to have a predilection for frequency modulated tones and to not respond to steady tones at all (Whitfield & Evans, 1965). In fact about 10% of the neurones from which Whitfield and Evans took single-unit recordings were of this type; most of the rest did have some response to steady tones, but their response to FM tones could not be predicted from the steady-state response. For example, some cells had wider bandwidths (or range of frequencies to which they would respond) for FM tones than for steady tones. Directional selectivity was another feature of a number of cells, such that some cells would respond only to upward or only to downward changes in frequency, regardless of the centre frequency. However, other cells would respond to upward changes in the low-frequency part of their response area and downward changes in the high-frequency part, with the cross-over point at the 'characteristic frequency' (frequency eliciting the strongest response to a steady tone). Finally, a minority of the A1 neurones tested did have responses to FM tones which could be predicted from their responses to steady tones: at low modulation frequencies, when the modulation crossed the boundaries of the response area (as determined by a steady tone) the cells responded when the frequency was inside the response area but not when it was outside it. At modulation rates above about 5 Hz, however, they fired only when the stimulus entered and exited the response area.

It is clear from the data of Whitfield and Evans (1965) that primary auditory cortex has some specialisation for the processing of modulated sounds, and this may well be the neural correlate of the psychophysical modulation detection channels discussed earlier. However, a note of caution must be introduced: most of the neurobiology in this area has been carried out in non-human animals, often cat. While it is likely that the broad organisation is similar for all higher mammals, it is also likely that there are species-specific differences which have to do with evolutionary specialisations. Amplitude and frequency modulations are known to be important for speech perception, a uniquely human behaviour. Therefore one cannot necessarily assume a straightforward relationship between groups of neurones responding to FM tones in the primary auditory cortex of the cat and the FM channels which have been described in human psychophysics.

Perception of different rates of modulation

An important point to appreciate in terms of the perception of frequency modulation, is that there are different percepts - and consequently different underlying mechanisms - which are associated with different rates of modulation. At modulation rates below about 10 Hz, the modulation can easily be followed by the listener, and the percept is one of a 'wobble' in the tone. At rates between about 10 Hz and 100 Hz the modulation becomes to fast too follow and is perceived as a roughness (or rather more pleasantly, a bird-like trill!) At rates above approximately 100 Hz, the modulation is not perceived as frequency change at all, but rather as a separate pitch at the frequency of the modulation rate (Green, 1976).

A modulated waveform consists of three components: the carrier and two sidebands which differ in frequency from the carrier by ± the modulation rate (in fact, FM has an infinite number of sidebands, but only the first two are relevant to this discussion). When the modulation rate is low, the three components are close together in terms of frequency: they are all contained within a single critical band, and the relative phases of components within a critical band can be detected by the auditory system. However, when the components have wide frequency separations and the sidebands are in different critical bands to the carrier, the differences in phase of the three components can no longer be analysed (cf. Moore, 1995). Instead of a modulation, a separate pitch is heard, which is similar to the residue or 'missing fundamental' phenomenon.

The conclusion that the auditory system uses phase information for the perception of low-rate modulations stems from the following empirical observations. At low rates of modulation, AM can be perceived when there is less energy in the sidebands than in equivalent FM (Zwicker, 1952; Sek, 1994). At equivalent carrier frequencies, modulation rates and depths, the only difference between FM and AM lies in the relative phase of the components. Therefore, differences in detectability of FM and AM can only stem from an analysis of these phase differences. At a point which Zwicker termed *Phasengrenzfrequenz*, the perceived differences between FM and AM disappear. The *Phasengrenzfrequenz* is at approximately 100 Hz modulation rate, but changes with carrier frequency and also across individuals. Past this point the perception of either FM or AM can no longer rely on phase information, but rather must use a non-linear mechanism (Green, 1976).

Phase sensitivity, FM and AM in dyslexia

A number of studies have examined sensitivity to temporal aspects of auditory stimuli in both dyslexia and specific language impairment. Temporal processing in this context refers to the processing of stimuli - such as amplitude or frequency modulated sounds - which probe sensitivity to phase information. As the phase of a waveform refers to its characteristics at a particular point in time, AM and FM detection depends on sensitivity to amplitude and frequency changes over time. This is distinct from processing sounds which follow one another in rapid sequence, as in the Auditory Repetition Test. The two types of 'temporal processing' are often confused in the literature, a grievance which is aired with vehemence by Studdert-Kennedy and Mody (1995); the distinction between the perception of stimulus change and the perception of rapidly presented stimuli can be thought of in terms of 'processing of rate' versus 'rate of processing'. The following discussion is concerned with 'processing of rate'.

In a comparison of adult dyslexics with normally-reading controls, McAnally and Stein (1996) used frequency-discrimination and binaural unmasking tasks to tap phase-locking in the auditory nerve (in which the auditory nerve fires only at a particular phase of the stimulating waveform). Note that a deficit in phase-locking would imply a lower-level deficit than previously suggested, as it is a mechanism that is not well-maintained past the level of the cochlear nucleus. The dyslexic group were significantly worse at making frequency discriminations around 1 kHz. They were also worse at binaural detection of a 1 kHz tone in noise, when the phase of the tone was inverted in one ear; however, they were as good as controls at this task when the phase of the tone was identical in both ears. This indicates that although their detection efficiency was normal, they were unable to make use of the interaural phase differences to enhance detection of the tone, as typical listeners do (Jeffress, Blodgett, Sandel & Wood, 1956). The conclusion that this group of dyslexics had deficient phase-locking was further supported by the finding of reduced amplitude in an electrophysiological measure of their frequency following responses (FFR): the FFR is a measure of phase-locking in the brainstem, and results from the synchronous discharge of phase-locked neurones. Finally, performance on both frequency discrimination and binaural unmasking was found to correlate significantly (in the region of $r = 0.5$) with reading ability. Strongly supporting the idea of a 'processing of rate' over a 'rate of processing' deficit was the finding that not only was phase information under-used in this dyslexic group, but that the same group was unimpaired on a gap detection task, and was able to separate out two tones with a gap of only 2 ms.

Further evidence in support of McAnally and Stein's (1996) conclusions was reported by Baldeweg , Richardson, Watkins, Foale and Gruzelier (1999), who used MMN to assess frequency and duration discrimination in adults with dyslexia. The MMN (mismatch negativity) is an auditory brain potential which is independent of attention, and is thus useful as an objective physiological measure to supplement behavioural findings. Baldeweg et al. found that the group of adults with dyslexia had abnormal MMN responses to changes in the frequency of pure tones, but not their duration. The MMN results corroborated the results of an active discrimination task, in which the dyslexic group again performed poorly on pitch, but not duration, discrimination. Finally, pitch but not duration discrimination correlated significantly with reading ability.

While Baldeweg et al.'s (1999) study replicates the frequency discrimination deficit reported by McAnally and Stein 1996), as well as its relationship to reading ability, it raises a question about the source of the deficit. MMN potentials are not generated in the brainstem, but at higher levels of the auditory system (Csepe, 1995); an MMN abnormality could as easily be put down to a deficit at these higher levels as to poor phase-locking in the auditory nerve or cochlear nucleus.

A further test of the phase-locking deficit hypothesis comes from Hill, Bailey, Griffiths and Snowling (1999), who capitalised on the fact that phase-locking only occurs for frequencies of up to approximately 5 kHz. Hill et al. obtained frequency discrimination detection thresholds at both 1 and 6 kHz. The group differences between adults with dyslexia and normally-reading controls were non-significant, although the dyslexic group had overall higher thresholds. However, for a subset of the dyslexic group whose thresholds were very high, frequency discrimination was poor at both 1 kHz and 6 kHz: given that phase-locking is not operational at 6 kHz, it cannot account for these results.

A different approach to measuring individuals' phase sensitivity uses the phenomenon of binaural unmasking. When a tone and a noise are presented simultaneously in both ears, the noise tends to mask the tone so that it becomes harder to detect; this happens when the tone and the masker are in the same relative phase. If the phase of the tone is inverted in one ear so that the tone and masker are in opposite relative phases, the tone is 'unmasked' and becomes detectable. One would predict that individuals who were insensitive to phase information would not show this unmasking effect, so if dyslexia is associated with insensitivity to phase information, individuals with dyslexia should show poor binaural unmasking thresholds. However, Hill et al. (1999) and Griffiths, Hill, Bailey and Snowling (2001) failed to reveal significant group differences in binaural unmasking thresholds when comparing individuals with dyslexia to normal readers.

The question of 'processing of rate' in dyslexia has also been addressed by investigators looking at sensitivity to frequency and amplitude modulation. Witton et al. (1998) obtained detection thresholds for frequency modulation at FM rates of 2 Hz, 40 Hz and 240 Hz. 2 Hz and 40 Hz FM were considered to be indicators of 'temporal processing' as their perception requires the analysis of phase information, whereas 240 Hz FM served as a control condition since at this rate temporal cues are no longer informative about the modulation (as discussed in the previous section). As predicted by the experimental hypothesis, a group of adults diagnosed as dyslexic had poorer sensitivity than controls to 2 Hz and 40 Hz FM, but not to 240 Hz FM. The usefulness of 240 Hz FM as a control condition was confirmed by the fact that 2 Hz and 40 Hz detection thresholds were highly intercorrelated, whereas neither correlated with 240 Hz thresholds.

Furthermore, high sensitivity to 2 Hz (and to a lesser extent 40 Hz) FM was associated with high coherent motion sensitivity, as assessed by a random dot kinematogram (Witton et al., 1998). This finding provides strong support for the wider interpretation of the 'magnocellular hypothesis' for dyslexia, discussed more extensively in chapter 2 of this thesis, as it implies a generalised deficit in processing dynamic stimuli, be they auditory or visual. However, it should be noted that the putative 'auditory transient system' is at the moment unelaborated. Though it may well be the case that there is a magnocellular equivalent in the auditory system, exploration of its nature and function is very much in its infancy. For example, there is recent evidence that there is a class of synapses in the mammalian auditory system which is particularly well suited to highly accurate transmission of timing information (Trussell, 1997). Anatomically, the strongest piece of evidence for 'auditory magnocellular' involvement in language disorders comes from the same dyslexic brains whose LGN was examined by Livingstone et al. (1991).* The medial geniculate nucleus (MGN) of the thalamus of these brains also turned out to be unusual. Although there was no overall difference in the mean area between dyslexic and control MGN neurons, the difference between cell areas of dyslexics and controls in the *left* MGN approached significance. Moreover, the distribution of neuronal sizes differed between the two groups, with dyslexics showing a relative paucity of large neurons and a relative excess of small neurons (Galaburda, Menard & Rosen, 1994). Given the limited knowledge we have of an 'auditory transient system', it is all the more striking that a deficit in processing dynamic auditory stimuli can be demonstrated behaviourally in dyslexia.

Witton et al. (1998) also reported that sensitivity to slow rates of FM and coherent motion both correlated significantly with performance (a combined measure of accuracy and speed) on a nonword reading task. The link between nonverbal auditory processing and phonological skill is necessary if the causal chain "auditory processing deficit → phonological deficit → oral language/reading deficit" is to have any credence. Witton, Talcott and colleagues have explored the relationship between sensitivity to dynamic stimuli and reading from a variety of angles. In a study of 32 unselected 10-year-old children, it was found that auditory FM sensitivity (for a rate of 2 Hz FM) could account for 24% of the variance in phonological processing, while motion coherence could independently account for 20% of the variance in orthographic skill (Talcott et al., 2000). Even more recently, 2 Hz FM and 20 Hz AM, but not 2 Hz AM or 240 Hz FM, were found to predict independent variance in nonword reading skill, in a sample of adults that included both normal and dyslexic

* Interestingly, the description in the literature of these individuals in life, suggests that they may have had oral language difficulties in addition to dyslexia (Bishop, in press).

readers (Witton, Stein, Stoodley, Rosner & Talcott, in 2002).

A slightly different approach was reported by Lorenzi, Dumont and Fullgrabe (2000), who looked at sensitivity to amplitude modulation and to vowel-consonant-vowel stimuli which had been processed to remove the original spectral information. This processing resulted in a stimulus in which a noise carrier was amplitude modulated according to the temporal envelope of the original speech sample. Children diagnosed with dyslexia were less sensitive than controls to simple AM stimuli, particularly at a slow modulation rate of 4 Hz. They were also poorer at identifying unprocessed VCV stimuli; in the case of the processed "speech-envelope noise" stimuli, they were initially similar to controls, who also had difficulty with the task; however, while the performance of the control group improved across sessions, this was not the case for the dyslexic group. It is interesting to note that AM modulations in the region of 4 Hz were identified as particularly important for speech perception in adults by Drullman et al. (1994b; Drullman, 1995). The link between relatively slow acoustic modulations, speech perception and subsequent phonological skill is becoming increasingly plausible.

Rationale for the current study

There are very few studies which have explored frequency modulation sensitivity in oral language impairment. The first to do so was reported by Stefanatos, Green and Ratcliff (1989), who recorded auditory evoked responses to frequency modulated tones in a group of children with expressive language impairment, a group of children with receptive language impairment, and a group of typically-developing children. The stimuli comprised a 1 kHz carrier tone which was frequency modulated at a rate of 10 Hz, to a depth of 20, 60, or 100 Hz. The cortical evoked response followed the frequency modulations in the control group and the expressive language impaired group. However, the receptive language impaired group showed no response at any of the modulation depths. The 'no-response' waveform was only seen for the other two groups when they were presented with a flat, unmodulated tone. The dramatic conclusion to be drawn from this study was that the receptive language impaired group lacked a cortical response to frequency modulation in sound.

This conclusion was re-examined more recently by Tomblin, Abbas, Records and Brenneman (1995) who failed to find any difference in the evoked responses to FM stimuli, between children with SLI and typically-developing children. This group modelled their stimuli and procedure very closely on Stefanatos et al. (1989), so the failure to replicate the original findings cannot be attributed to methodological differences. On the other hand, the children described as 'receptively language impaired' differ markedly in the two studies. Stefanatos et al. described a number of the children in their group as showing characteristics of Landau-Kleffner syndrome, a neurological disorder characterised by epilepsy, and often associated with severe language difficulties. In contrast, Tomblin et al. were working with children with SLI, a less extreme disorder which by definition has no obvious neurological correlates. This explanation for the discrepant findings is supported by the report of Stefanatos (1993), who found no cortical response to FM stimuli in children diagnosed with Landau-Kleffner syndrome. The total lack of cortical response to FM is therefore probably a feature of Landau-Kleffner syndrome, but not SLI.

This does not necessarily mean, however, that sensitivity to FM is intact in SLI. First of all, although Landau-Kleffner syndrome is not a specifically linguistic disorder, it does involve severe phonological impairment - it may well be the case that the FM deficit, whatever its neurological roots, underpins the phonological problems. Secondly, if the studies relating sensitivity to FM and AM to speech perception and phonological skill are correct, it is plausible that even a relatively mild impairment of modulation sensitivity may contribute to the phonological difficulties often described in SLI. This possibility could best be assessed by a behavioural study comparing a well-defined group of children with SLI and matched controls on FM detection, and an analysis of the relationship between FM sensitivity and performance on phonological tasks.

Bishop, Carlyon, Deeks & Bishop (1999) obtained FM detection thresholds for a group of language impaired children selected from a twin sample participating in a larger study; the age- and IQ-matched controls were drawn from the same population. The children were tested on 2 Hz and 20 Hz FM (but not 240 Hz FM), and although there was a trend for higher thresholds in the language-impaired group, this was not significant. Nor were there any significant correlations between FM sensitivity and performance on phonological tasks (nonword reading and nonword repetition). This is contrary to what would be expected from Witton et al.'s (1998) findings, and raises the possibility that if FM deficits were consistently obtained in dyslexia but not in SLI, it may be wrong to view the two conditions as having similar aetiologies.

The current study is an attempt firstly to clarify whether language impaired children do or do not have low sensitivity to slow rates of FM, and secondly to confirm whether FM sensitivity is related to phonological skill, regardless of language status.

Method

Participants

The same group of children who participated in the coherent motion study reported in chapter 2, were tested in the current study. Testing took place approximately 6 months before the coherent motion study. Nonverbal ability and language measures used to select children for language-impaired or control groups are as reported in chapter 2. One additional child in the SLI group is included in the current study. Means and standard deviations for the age and Raven's matrices scores for each group are given below (Table 3.1), as these were the criteria on which groups were matched.

Mean (SD) *min - max*	**SLI** ***n* = 11**	**PLI** ***n* = 4**	**SLI-Control** ***n* = 12**	**PLI-Control** ***n* = 4**
Age **(years:months)**	9:4 (1:10) 6:5 - 11:9	8:4 (0:11) 7:0 - 8:10	9:6 (1:9) 6:9 - 11:11	8:4 (0:9) 7:3 - 8:10
Raven's Matrices	101.82 (11.16) 86 - 125	115.50 (9.15) 103 - 125	100 (8.08) 88 - 114	119.75 (6.08) 114 - 125

Table 3.1: Group profiles, in terms of age and nonverbal ability.

Procedure: Psychoacoustic tasks

The method used in this experiment was based very closely on the procedure used by Witton et al. (1998), as part of the motivation for the study was to replicate their findings with adults with dyslexia in a group of children with SLI.

Two rates of frequency modulation were investigated: 2 Hz and 240 Hz. 2 Hz was the dynamic stimulus, for which participants had to rely on the temporal properties of the tone to detect the FM. 240 Hz was the static stimulus which could be perceived using only spectral cues. The hypothesis was therefore that children with SLI would have difficulty detecting 2 Hz but not 240 Hz FM compared to control children.

The psychoacoustic task used to estimate frequency modulation detection thresholds used a 2-alternative forced choice (2-AFC) paradigm. Participants were presented with two tones, one of which was a pure tone and one of which was frequency modulated. They then had to decide whether the modulated tone came first, in which case they pressed the 'z' key on a computer keyboard, or last, in which case they pressed the 'm' key. The instruction which worked best for most children was "listen for the wobble" (for 2 Hz). A number of children requested that I press the keys for them, in which case they said "first" or "last".

The 2 Hz and 240 Hz conditions were presented in separate sessions, each lasting about 20 minutes. The order of the sessions was counterbalanced across subjects. Before testing started, there was a brief practice period in the form of a rough staircase procedure, which was used to determine the maximum modulation depth for that subject. Six modulation depths were used, the lowest always being zero, with 10 trials at each depth. Presentation of different modulation depths was randomised. The order of the target and distracter in each trial was pseudo-randomised, to avoid large blocks of consecutive trials in which the correct response was on the same key, as this could have resulted in subjects ceasing to attend to the stimuli.

A psychometric function was constructed from the data, relating the number of trials the subject responded to correctly with the modulation depth. Modulation depth was reported in terms of the modulation index, which is modulation depth in Hz divided by the rate of modulation (in Hz). The psychometric function was then fitted with a Weibull function (Macmillan & Creelman, 1991), and a detection threshold estimated at the 75% correct level on this function (that is, the modulation depth at which subjects would obtain 75% correct on the fitted function).

The tones were generated using Tucker Davies Technologies System III equipment, and were presented to subjects using Sennheiser headphones (HD25). All testing took place in a quiet room. The tones were 1000 ms in duration, with 500 ms inter-stimulus interval (ISI). Stimuli were gated on and off with 20 ms rise/fall times. Frequency modulation in the target was sinusoidal, and the carrier frequency of the tones was 1000 Hz. The tones were presented at a comfortable sensation level of approximately 60 dB SPL.

Procedure: Phonology tasks

Nonword Reading

The Graded Nonword Reading Test (Snowling, Stothard & Mclean, 1996) is a test of phonological decoding. A list of 20 nonwords is presented to the child, who is asked to read them aloud. The nonwords increase in length and complexity as the test progresses, and the number of correct responses is summed and converted to an age-scaled score (population $M = 100$, $SD = 15$).

Nonword Repetition

Phonological short-term memory was estimated using the Children's Test of Nonword Repetition, or CNRep (Gathercole & Baddeley, 1996). Children are required to repeat a set of 40 nonwords, which follow the phonotactic rules of English, and whose length and complexity increases as the test progresses. The length of nonwords varies from one to five syllables. Children's correct responses are summed and converted to age-scaled scores (population $M = 100$, $SD = 15$).

Phonological Discrimination

The Phonological Discrimination test (Bridgeman & Snowling, 1988) comprises 60 pairs of monosyllabic words and nonwords which differ either by one phoneme (e.g. *vis* - *vit*), or in the order of the final consonants (e.g. *vist* - *vits*). Only the phonemes /t/ and /s/ and cluster /ts/ and /st/ are included in this task, as their correct perception is particularly important for grammatical inflection. Children were required to give a same/different judgement on all 60 pairs. No age-standardised scores are available for this test, so raw scores are reported.

In addition to the phonology tasks, a digit-span task (Briscoe, Gathercole & Marlow, 1998) was administered to each child, as a test of non-phonological short-term memory. A series of digits (the shortest series being 2 digits long, and the longest 8) was read aloud to the child at the rate of one digit per second. The child then repeated the series back in the same order. Testing continued, with four digit-series of each length, until the child responded incorrectly to all series of a given length (including a fifth 'reserve' item). The scores reported for this test are the length of the longest series each child could repeat correctly; in the absence of age-standardised scores, raw scores are reported.

Results

Group comparisons

The experimental hypothesis predicted that children with language impairment would obtain significantly higher thresholds than typically developing children for slow (2 Hz) but not fast (240 Hz) rates of frequency modulation. Such a finding would support the view that children with SLI have impaired processing of dynamic auditory stimuli. It would also support the view that SLI and developmental dyslexia share an underlying deficit in the processing of such stimuli.

The graphs in Figure 3.1 show the log transformed FM detection thresholds for the four groups of participants; the graphs include data from all subjects, excluding three cases in which it was impossible to obtain a threshold. On initial inspection, it appears as though in both SLI and PLI, the experimental groups have a higher mean threshold than their respective control groups, in the case of 2 Hz FM but not 240 Hz FM.

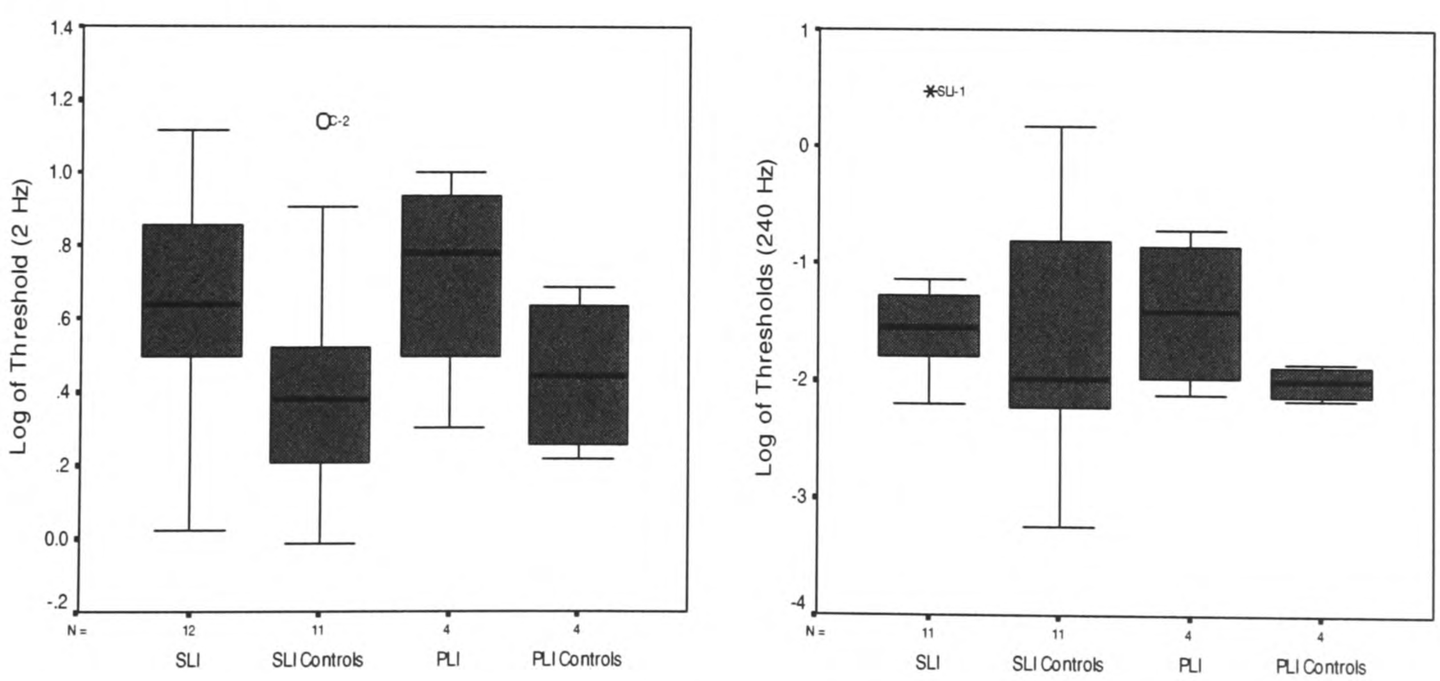


Figure 3.2: Frequency modulation detection thresholds for 2 Hz (left) and 240 Hz (right) modulation rates. Includes all obtained thresholds. Boxplots indicate the median, quartiles and extremes of the distribution.

There also appears at first to be little overlap in the thresholds of the SLI group and the SLI Control group in the 2 Hz condition. However, it is obvious that the variability in performance within each group is very large, in both 2 Hz and 240 Hz conditions, as shown by the lines indicating range in the boxplots (particularly for the SLI and SLI Control groups). It should be noted that all FM detection thresholds reported below, whether in graphs or statistical analyses, were $\log_{10}$ transformed to normalise the distribution.

On closer examination of the data it became clear that not all threshold estimates could be accepted as valid indicators of the subject's performance on the task. When the Weibull function was fitted to the psychometric function constructed from the data, both threshold and variance values were calculated. Many of the 'data functions' did not approximate psychophysical functions, possibly as a result of inattention on the part of the participants; this resulted in a poor match between the fitted functions and the 'data functions'. A variance level of 0.3 discriminated reasonably well between acceptable and non-acceptable fitted functions. Consequently, all data for subjects whose fitted functions had a variance of 0.3 or greater were discarded. This meant that thresholds from different sets of children remained for the 2 Hz versus 240 Hz FM conditions.

2 Hz FM: Group comparisons for SLI

Roughly half the threshold estimates for the 2 Hz condition were discarded according to the variance < 0.3 criterion. Although this left very small groups (SLI n = 7, SLI-Control n = 6, PLI n = 2, PLI-Control n = 1), the remaining threshold estimates could now be considered a reliable indicator of subjects' performance. Judging from Figure 3.3, which shows 2 Hz FM detection thresholds for the newly specified groups, the median thresholds for the SLI and SLI Control groups still appear different; however, it is obvious that there is not only a big overlap in scores between the two groups, but also that the overall range of performance is nearly identical.

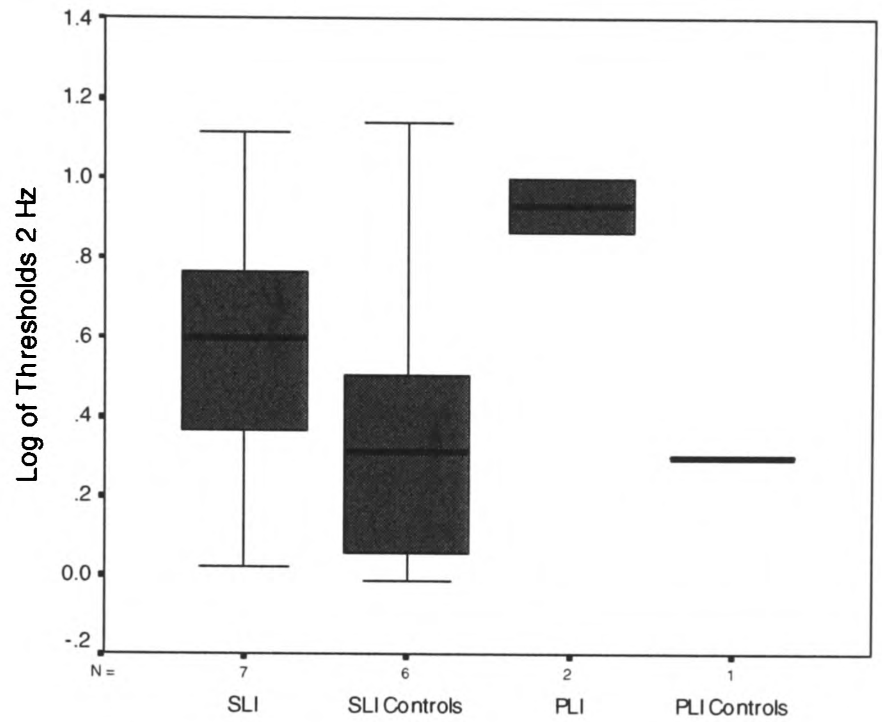


Figure 3.3: Frequency modulation detection thresholds, for 2 Hz FM. Includes only data from participants for whom variance between fitted and data functions was less than 0.3.

An independent samples *t*-test was used to compare the means of 2 Hz FM detection thresholds for the SLI and SLI-Control groups; it revealed no significant difference between the groups (Table 3.2).

Group	***n***	***M***	***SD***	***t***	***df***	***p***
SLI	7	4.96	4.06	0.42	11	.68
SLI-Control	6	3.91	4.94			

Table 3.2: 2 Hz FM detection means for SLI and SLI-Control groups, and independent-samples *t*-test.

The variance between the data-derived and fitted functions in the two groups was also compared; this could be seen as an indication of ability to do the task, and might be expected to differ between the two groups. There was no significant group difference on this measure (Table 3.3).

Group	***n***	***M***	***SD***	***t***	***df***	***p***
SLI	7	.21	.05	-0.03	11	.97
SLI-Control	6	.21	.06			

Table 3.3: 2 Hz FM function variance means for SLI and SLI-Control groups, and independent-samples *t*-test.

Finally, it should be clarified that although data was treated independently of subject identity, so that the original matching between children with SLI and their controls was lost, the groups were still reasonably well matched in terms of age and nonverbal ability (Table 3.4).

Mean (SD)	**SLI** (n = 6)	**Control** (n = 11)	t	df	p
Age	9;1 (1;10)	9;10 (1;10)	-0.68	11	.51
Raven's	105.4 (9.3)	99.7 (10.17)	1.07	11	.31

Table 3.4: Age and Raven's score means for redefined SLI and SLI-Control groups, and independent-samples t-tests.

2 Hz FM: PLI

The PLI and PLI control groups were too small to merit statistical analysis. However, the very large difference in mean threshold estimates is notable: PLI (n = 2) M = 8.7, SD = 1.87; PLI Controls (n = 1) M = 1.97.

240 Hz FM: Group comparisons for SLI

Inspection of Figure 3.4, which shows detection thresholds for 240 Hz FM, suggests similar performance across all groups of participants. It is interesting that the range of performance in the SLI Control group is greater than in the SLI group; this may be because of the larger size of the group. It is also interesting that in this condition, there was a greater number of well-fitted functions in all groups except SLI, suggesting that for most children (but not SLI) 240 Hz detection is easier than 2 Hz detection. This is reflected in the greater number of scores remaining in the groups after discarding all functions with a variance > 0.3: SLI n = 6, SLI Controls n = 11, PLI n = 2, PLI Controls n = 3.

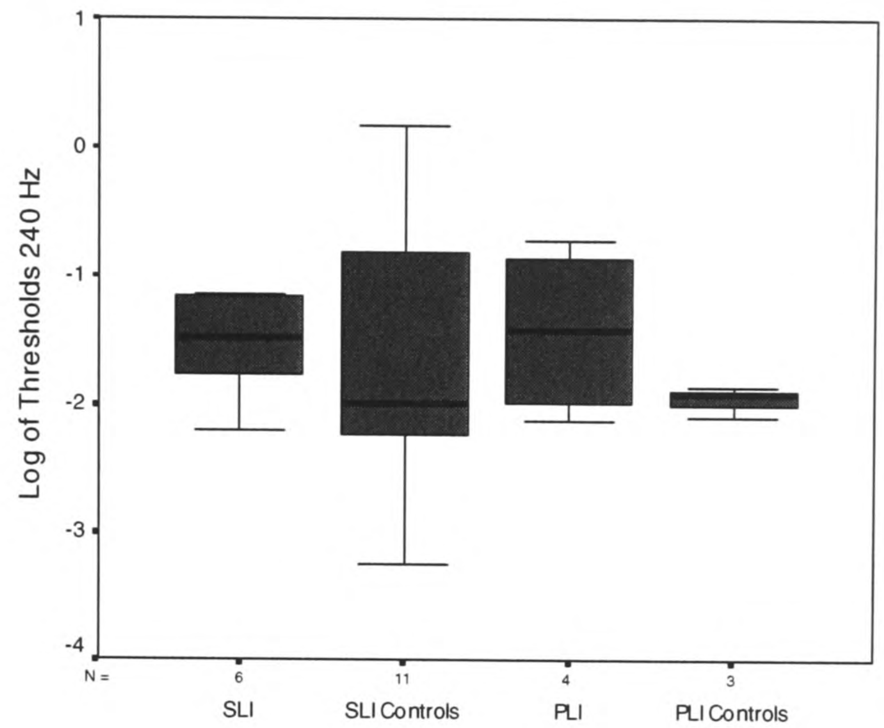


Figure 3.4: Frequency modulation detection thresholds, for 240 Hz FM. Includes only data from participants for whom variance between fitted and data functions was less than 0.3.

An independent-samples *t*-test confirmed that 240 Hz FM detection threshold estimates did not differ significantly between the SLI and control groups (Table 3.5).

Group	*n*	*M*	*SD*	*t*	*df*	*p*
SLI	6	-1.54	0.41	0.02	14.09	.98
SLI-Control	11	-1.55	1.06			

Table 3.5: 240 Hz FM detection means for SLI and SLI-Control groups, and independent-samples *t*-test.

The variance between fitted and data-derived functions also did not differ significantly between the two groups (Table 3.6).

Group	*n*	*M*	*SD*	*t*	*df*	*p*
SLI	6	-0.73	0.13	0.08	15	.94
SLI-Control	11	-0.72	0.15			

Table 3.6: 240 Hz FM function variance means for SLI and SLI-Control groups, and independent-samples *t*-test.

Again, as in the 2 Hz condition, the SLI and control groups were reasonably well matched on age and nonverbal ability, despite the uneven sizes of the groups (Table 3.7).

Mean (SD)	**SLI** (n = 6)	**Control** (n = 11)	t	df	p
Age	10;4 (1;6)	9;6 (1;9)	0.96	15	.35
Raven's	104.8 (8.0)	99.5 (8.3)	1.27	15	.22

Table 3.7: Age and Raven's score means for redefined SLI and SLI-Control groups, and independent-samples t-tests.

240 Hz FM: PLI

Once again, the very small numbers in the PLI and PLI Control group do not justify statistical analysis. As in the 2 Hz condition, the difference in detection thresholds is dramatic, with the PLI group having thresholds an order of magnitude greater than the control group (PLI $n = 2$, $M = .10$, $SD = .12$; PLI Controls $n = 3$, $M = .01$, $SD = .00$).

Age effects

Detection thresholds for 2 Hz FM correlated significantly with age, such that the older the participant, the lower (i.e. better) the detection threshold [r (15) = -.70, $p < .01$]. This correlation was weaker for 240 Hz FM, for which there was a non-significant trend [r (23) = -.35, p = .09]. These correlations may be due in part to outliers, since the highest detection thresholds came from the youngest participants.

Young outliers excluded

Given the relationship with age, particularly in the 2 Hz condition, it seemed justifiable to re-examine the data with the outlying data points - which came from the youngest subjects - removed (Figure 3.5).

Although the detection thresholds for the outliers are clearly very different from those of the rest of the subjects, there were still no significant group differences. However, there was a trend in the predicted direction (Table 3.8).

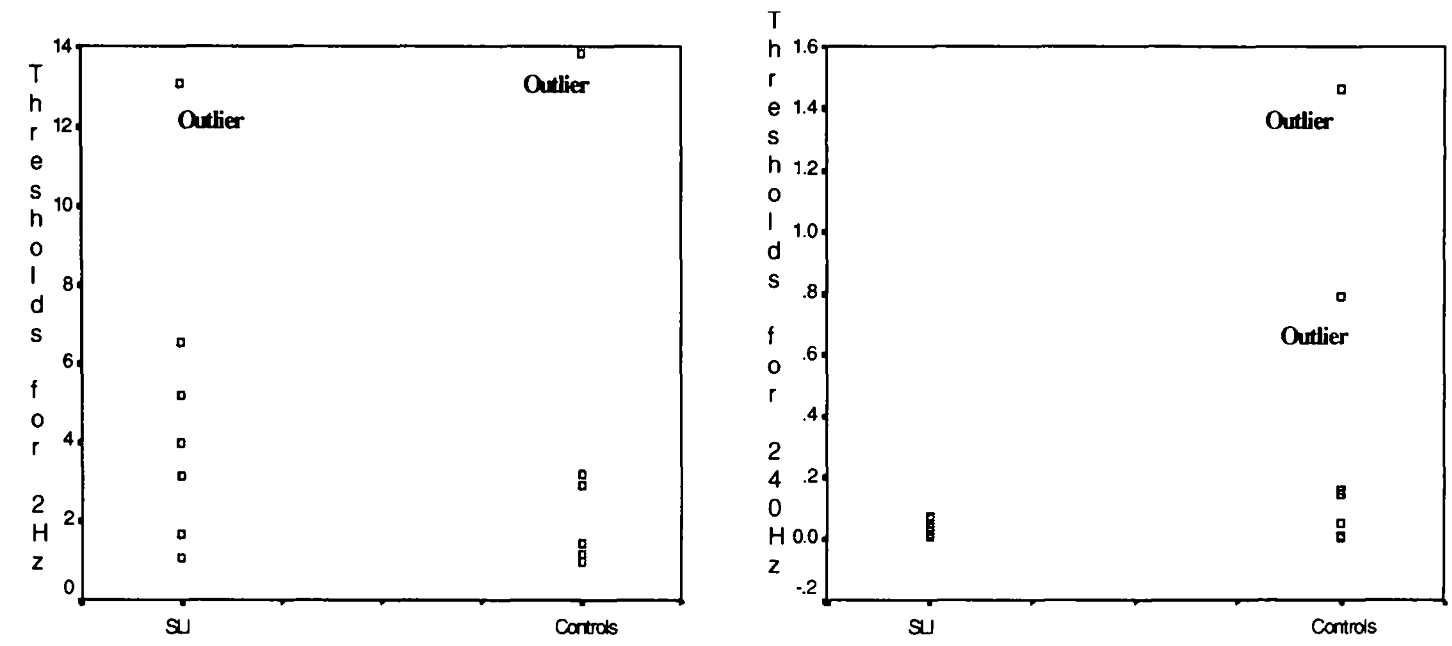


Figure 3.5: Scatterplots showing outliers for FM detection thresholds (in modulation index), for SLI and SLI control groups, at modulation rates of 2 Hz FM (left) and 240 Hz FM (right).

Mean (SD) *n*	**SLI**	**Control**	*t*	*df*	*p*
2 Hz	0.48 (0.30) $n = 6$	0.23 (0.24) $n = 5$	1.48	9	.17
240 Hz	-1.54 (0.41) $n = 6$	-1.89 (0.79) $n = 9$	1.02	13	.33

Table 3.8: 2 Hz and 240 Hz FM detection means for SLI and SLI-Control groups, and independent-samples *t*-tests. Excludes data from outliers.

2 Hz and 240 Hz FM

A correlation coefficient was obtained for the relationship between performance on the 2 Hz FM task and the 240 Hz FM task [r_s (9) = .66, p = .04]. Data was only used from participants who had reliable threshold estimates in both conditions; this included four participants from the SLI group and 6 from the SLI Control group (none from the PLI or PLI Control groups). This correlation is strong enough to confirm that if a child was able to do the task in one condition it was likely that they would also be able to do it in the other condition; however, it is unexpected, given the different mechanisms considered to underlie perception of the two rates.

Frequency modulation and phonology: Correlational analysis

In addition to exploring the FM sensitivity of children identified as SLI, the current study is concerned with the relationship between sensitivity to slow rates of FM and language performance, particularly phonology, regardless of the language status of the individual. It is important to keep in mind, however, that the children with language impairment perform consistently more poorly than control children on all three phonological tasks used. This point is illustrated in Figure 3.6, which compares mean scores for the SLI and control groups on the nonword reading, nonword repetition, and phonological discrimination tasks.

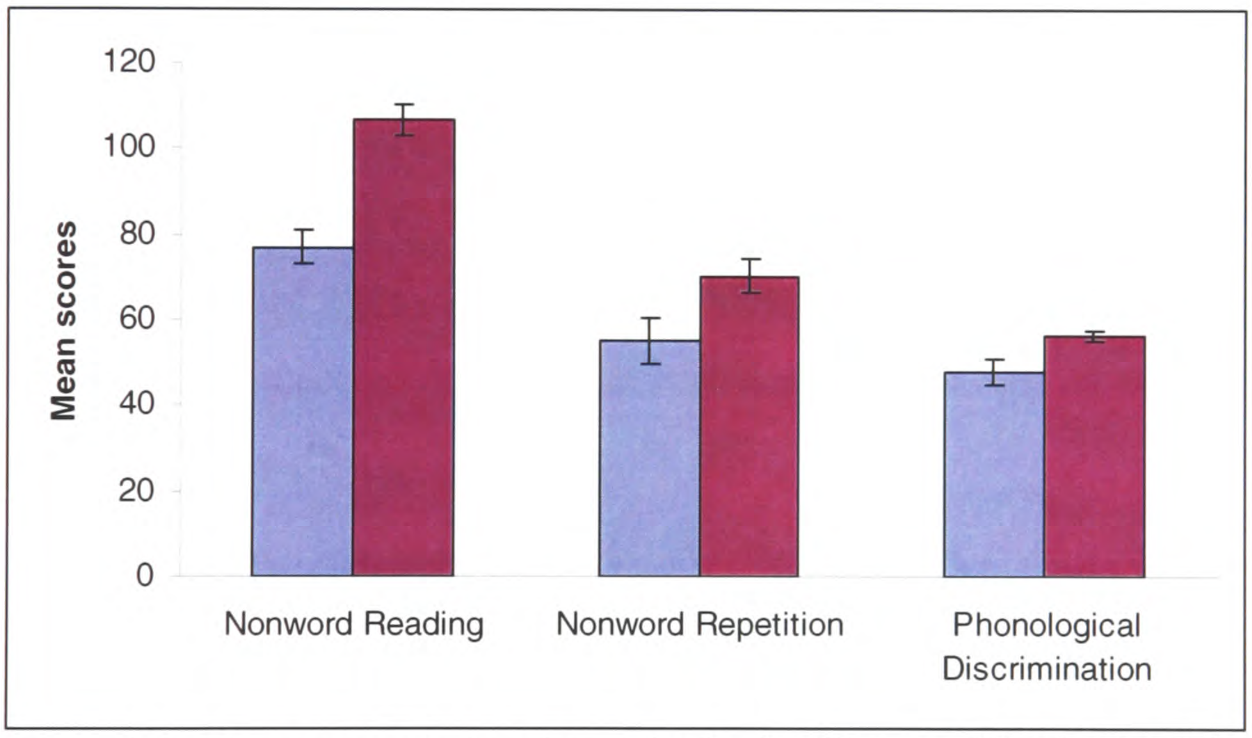


Figure 3.6: Mean scores on phonology tasks for the SLI group (blue bars) and the Control group (maroon bars). Note that phonological discrimination performance is reported in terms of raw scores (total correct out of 60), while nonword reading and nonword repetition performance is presented in terms of age-scaled scores (based on population $M = 100$, $SD = 15$).

A set of non-parametric correlational analyses (Table 3.9) showed that there was a trend toward correlation between 2 Hz FM thresholds and scores on most of the language measures, but not the non-language measures (Raven's matrices and digit span). There was no such trend for 240 Hz FM. It should be noted that in the case where age-norms were not available for a test (phonological discrimination and digit span), age was partialled out of the correlation.

	2 Hz FM *n = 16*	**240 Hz FM** *n = 24*
Raven's Matrices	-.04	.13
BPVS	-.39	.00
Nonword Reading	-.28	-.24
Nonword Repetition	-.31	-.15
Phonological Discrimination*	-.44	-.09
Sentence Recall	-.34	-.26
Digit Span*	-.16	-.08

Table 3.9: Spearman's correlations between FM detection thresholds and verbal & nonverbal measures. Includes data from all participants whose FM detection thresholds were retained.
*Age partialled out of correlation.

The correlational analyses only partially confirmed the experimental prediction that 2 Hz FM would correlate with phonological performance: though the pattern of results was as predicted, it did not reach statistical significance. This was very likely due to the small size of the groups, particularly for 2 Hz FM. It is also possible that floor effects in the SLI group, most notably in the nonword reading task, may have masked an existing relationship.

An alternative approach to bivariate correlations, which is unaffected by floor effects, is a median split procedure: did children who performed below the median on a phonological task have higher FM thresholds than children who performed above the median?

Median split: Nonword Reading

The median score on the nonword reading for the sixteen children whose 2 Hz FM thresholds were retained was 91.5. An independent-samples *t*-test comparing the mean detection thresholds for 2 Hz FM, showed that the group of children scoring above the nonword reading median score were significantly more sensitive to 2 Hz FM than the children scoring below the median (Table 3.10).

Group	*n*	*M*	*SD*	*t*	*df*	*p*
Below median	8	0.73	0.29	2.38	14	**.03**
Above median	8	0.33	0.38			

Table 3.10: 2 Hz FM detection means for groups derived from nonword reading median split, and independent-samples *t*-test.

In contrast, there was no significant relationship between nonword reading score and 240 Hz FM detection when a median split was calculated for the 240 Hz group [t (22) = 1.64, $p > .05$]. In addition, the two groups (below and above median) did not differ significantly in terms of age or nonverbal ability. These results suggest that performance on nonword reading predicts sensitivity to slow but not fast rates of frequency modulation, which is in accordance with the findings reported by Witton et al. (1998) and Talcott, Witton et al. (2000). It is particularly striking that there was virtually no overlap of 2 Hz FM thresholds between the below- and above- median groups (Figure 3.7).

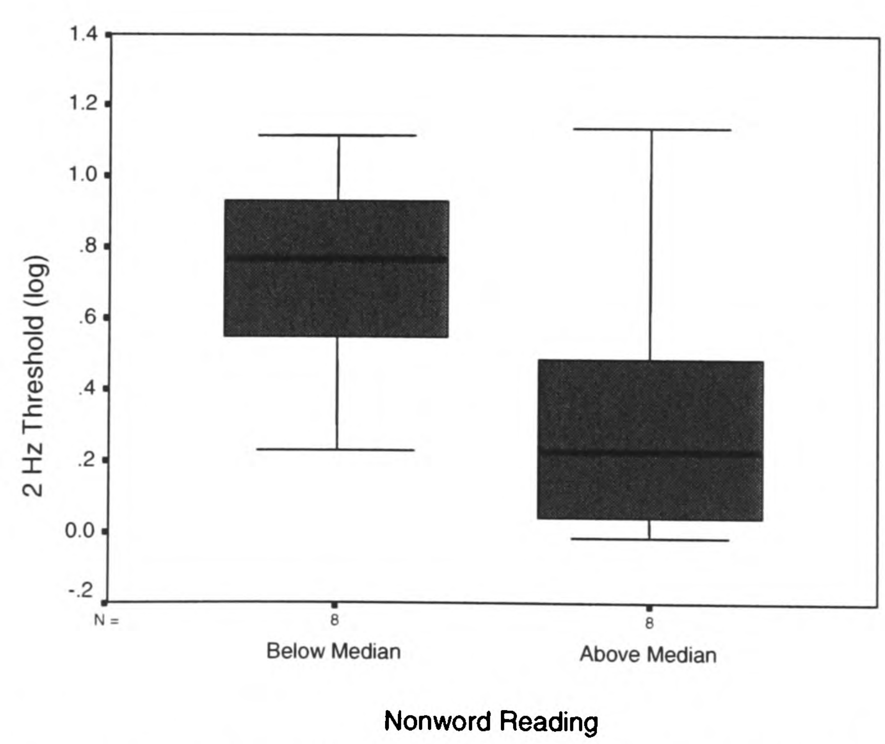


Figure 3.7: 2 Hz FM detection thresholds for groups derived from nonword reading median split.

Median split: Nonword Repetition

The median nonword repetition score for the fourteen children whose 2 Hz FM threshold were retained was 62. This is an age-scaled score. The two groups derived from the nonword repetition median split did not differ significantly in terms of age or nonverbal ability. While FM detection thresholds were not significantly different between the above- and below-median groups for either rate of FM, it is clear that there was a strong trend in the predicted direction for 2 Hz FM (Table 3.11) but not 240 Hz FM [t (22) = 0.24, $p > .05$].

Group	***n***	***N***	***SD***	***t***	***df***	***p***
Below median	7	0.75	0.30	2.02	12	.07
Above median	7	0.35	0.42			

Table 3.11: 2 Hz FM detection means for groups derived from nonword repetition median split, and independent-samples *t*-test.

As with nonword reading, there was very little overlap in 2 Hz FM detection thresholds between the group of children with good nonword repetition versus the group with poor nonword repetition scores (Figure 3.8).

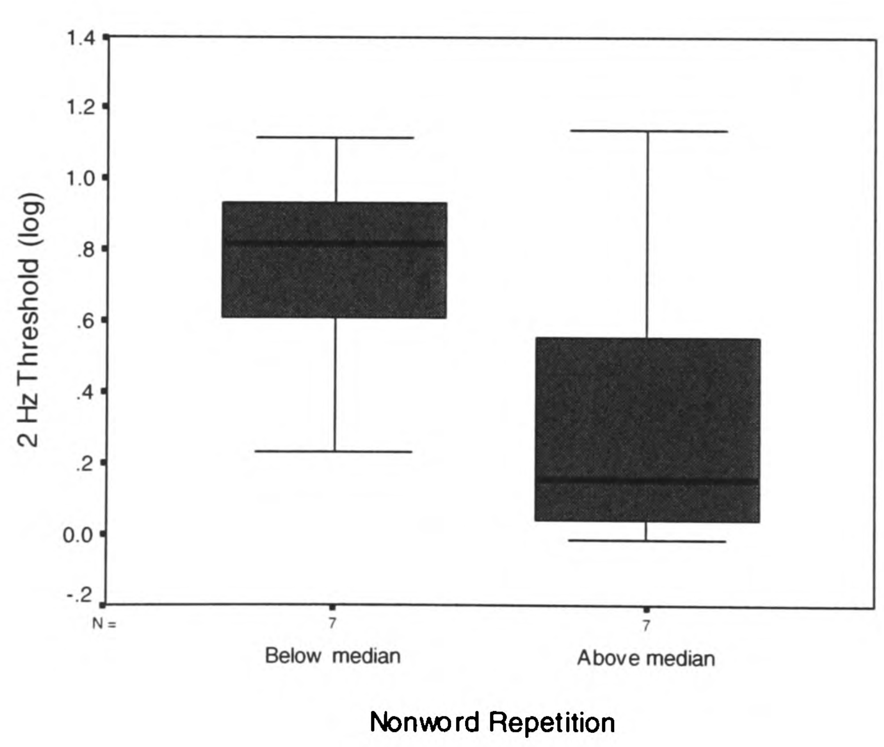


Figure 3.8: 2 Hz FM detection thresholds for groups derived from nonword repetition median split.

Median split: Phonological Discrimination

Performance on 2 Hz FM was strongly predicted by being below or above the median split in the phonological discrimination task (Table 3.12). The median score for this task was 54, for the 2 Hz FM data. Note that the phonological discrimination scores are not standardised for age, and so part of the relationship may be explained by age; indeed, the above- and below- median groups did differ significantly on age [t (12) = 2.33, $p < .05$], although not on nonverbal ability. However, the correlation reported earlier which did take age into account found a strong trend for a relationship between phonological discrimination ability and performance on 2 Hz FM, though it did not reach statistical significance. The 240 Hz FM condition, in contrast to 2 Hz FM, was not strongly related to phonological discrimination ability [t (22) = 1.42, $p >$ .05].

Group	***n***	***M***	***SD***	***t***	***df***	***p***
Below median	9	0.76	0.32	3.78	14	**.00**
Above median	7	0.23	0.22			

Table 3.12: 2 Hz FM detection means for groups derived from phonological discrimination median split, and independent-samples t-test.

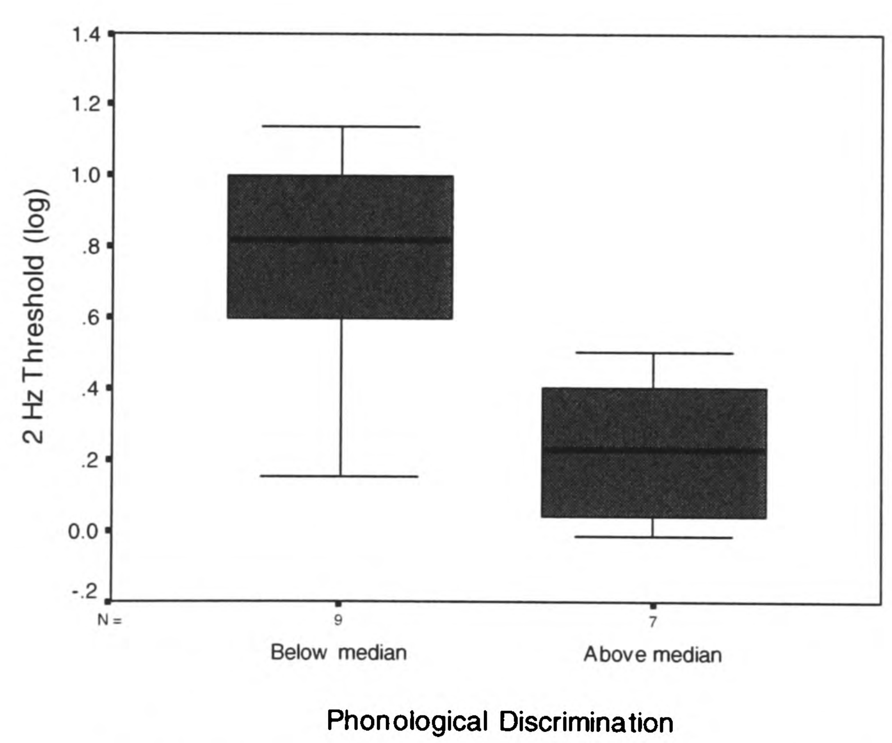


Figure 3.9: 2 Hz FM detection thresholds for groups derived from phonological discrimination median split.

Once again, as with nonword reading and nonword repetition, there was effectively no overlap in the distributions of 2 Hz FM thresholds between the above- and below-median groups (Figure 3.9).

The measure of nonverbal ability – Raven's matrices – revealed no similar relationship with 2 Hz FM detection, using the median split procedure. The two more general language measures – BPVS and CELF-Recalling Sentences – also showed no clear relationship with 2 Hz FM. All the measures which did show a strong relationship (nonword reading, nonword repetition, and phonological discrimination) have a primary phonological component. In contrast, 240 Hz thresholds were not predicted by any of the measures, phonological or otherwise. It is worth noting that many, though not all, of the same children were in the below- and above-median groups across the three phonological tasks.

Frequency modulation and motion coherence sensitivity

Since the same children participated in both the current experiment and the coherent motion experiment reported in chapter 2, it was possible to evaluate the relationship between sensitivity to visual and auditory dynamic stimuli. According to the magnocellular hypothesis, and as supported by the findings of Witton et al. (1998), there should be a significant correlation between the two.

There was a near-significant correlation between coherent motion thresholds and slow (2 Hz) frequency modulation [r_s (13) = .51, p = .06]. As both coherent motion and 2 Hz FM thresholds are strongly related to age, part of the strength of their relationship might be attributable to age. Partialling out age left a very low correlation coefficient [*pr* (12) = -.03, $p > .05$], suggesting that age accounts for nearly all the apparent relationship between coherent motion and 2 Hz FM. According to the magnocellular hypothesis, coherent motion thresholds would not be predicted to relate to fast rates of frequency modulation, since these are not processed as dynamic stimuli. However, the situation here appears to be similar to that for slow rate FM: the correlation between motion thresholds and 240 Hz FM was [r_s (23) = .47, $p < .05$], and dropped to a negligible level [*pr* (22) = .05, $p > .05$] when age was partialled out.

Neither slow nor fast frequency modulation thresholds correlated with form coherence, which is in line with the predictions of the magnocellular hypothesis. However, this may well be attributable to the lack of an effect of age on form coherence detection thresholds.

In short, as far as the results of these two studies can show, any apparent relationship between sensitivity to visual dynamic stimuli (motion) and auditory dynamic stimuli (frequency modulation) can be accounted for by a third factor: age.

Discussion

The purposes of this study were twofold: to determine whether children with SLI show a deficit in the perception of slow rates of frequency modulation, and to confirm the relationship between FM sensitivity and phonological skill reported by Witton and colleagues (Witton et al., 1998, 2002; Talcott, et al., 2000). It was impossible to draw firm conclusions about either of these issues, because there was not enough data obtained in the psychophysical task which was suitable for analysis. In the 2 Hz FM condition, nearly half the thresholds had to be discarded as the distribution of data points did not approximate any legitimate psychophysical function. In the 240 Hz FM condition, although almost all the thresholds were retained from the control group, half were lost from the SLI group.

The reasons for this carnage are most probably directly related to the nature of the task presented to the participating children. The vast bulk of psychophysical work in the past has been carried out with adult participants, often the experimenters themselves or other people who are highly trained and practised on this kind of task. They tend to be not only used to the test situation, but also highly motivated and attentive, and able to give maximum performance in what is fundamentally an unrewarding task. It is perhaps unrealistic to expect young children to be able to do the same.

Children with SLI in particular are often found to have attentional difficulties, and there is substantial overlap between incidence of SLI and attention deficit hyperactivity disorder (ADHD). The Ottawa Longitudinal Study, which followed one in three of all 5-year olds in the region to assess comorbidity of speech and language disorders and psychiatric disorders, reported that 30% of children with speech or language impairment were also diagnosed with ADHD (Beitchman, Nair, Clegg, Ferguson & Patel, 1986; Beitchman, Hood & Inglis, 1990). Conversely, up to two thirds of children with ADHD also show language disorders (Love & Thompson, 1988), and children who have both SLI and ADHD are significantly more likely to have first-degree relatives with language disorders than children with SLI but no diagnosed attention deficit (Kovac, Garabedian, Du Souich & Palmour, 2001). Suggested explanations for this high degree of overlap between the two conditions range from the social to the neuropsychological. For example, the Ottawa Longitudinal Study found that within the language disordered group, children who could be classified as having comprehension deficits were the most likely to show distractible or hyperactive behaviour; it is plausible that children who are not gaining much information from social discourse or oral teaching in the classroom will lose interest and begin to behave inappropriately, earning themselves the label of 'hyperactive' (Beitchman, 1996). An alternative possibility is that fronto-striatal dysfunction underlies the lack of executive control seen to a greater or lesser degree in both SLI and ADHD. However, a recent study by Williams, Stott, Goodyer & Sahakian (2000) reported relatively specific problems in the inhibitory control of attentional selection in children with ADHD, whether they were diagnosed with SLI or not, but no such problems for children with SLI but no ADHD diagnosis. Williams et al. concluded that despite the frequency of co-occurrence, the two disorders do not share an underlying impairment of executive function.

However, even for children whose inattentiveness is within normal bounds and hardly merits a diagnosis of ADHD, the following behaviour during a boring task is not unusual:

> ...the LI children would sometimes gaze around the test room, play with the headphones, or slump, glass-eyed, while the sentences were being presented. (Stark & Montgomery, 1995, p. 150).

There were a number of features of the psychophysical procedure used in the current study that may have contributed to poor task performance, whether through inattentiveness or not. First of all, there was little feedback following a response: the screen was black with a column of numbers indicating the trial number, with a green font for a correct and red for an incorrect response. Although this level of feedback is adequate for a patient adult, it is not sufficiently motivating for young children, particularly ones prone to inattention.

Secondly, the task was paced: although the intervals were sufficiently long for children to make a response if they were concentrating, if they were not concentrating the experimenter was unable to delay the onset of each trial until the child was focused on the task again.

Thirdly, the psychophysical method used was that of constant stimuli. Once the approximate region of the child's FM threshold was established during the practise trials, 10 trials for each of 6 modulation depths in this region were presented in a quasi-randomised way: the modulation depth in each trial was independent of the child's response to the previous trial. If a child made a mistake, for whatever reason, it was as likely as not that the next trial would be even more difficult; this situation was found to have a very de-motivating effect.

Finally, the most common complaint made by children in any group was: "I heard the wobble but I can't remember where it was". Each trial contained only two tones, so it is surprising that the memory load should have been such an impediment. In Tallal & Piercy's (1973a, 1973b) early work with the Auditory Repetition Test, as long as the inter-stimulus interval was long, performance for children with SLI did not begin to fall off until the sequences increased to more than three tones. Two tones could therefore reasonably be expected to be unproblematic. Furthermore, the alternative of using only one tone and asking whether an FM is present or absent introduces an unacceptable risk of response bias. It is clear that an improved task would have to reduce the memory load (although keeping the 2-AFC format), and be more motivating for young children. The questions of pacing and relating the difficulty of each trial to the child's current performance would also have to be addressed.

Despite the methodological difficulties, some discussion of the current findings is relevant. The first is the lack of a group difference between children with language impairment and children with typical language on the slow rate of frequency modulation. There are two possible explanations for this finding: either children with SLI have normal FM sensitivity (which leaves open, but does not encourage, the possibility of a different non-verbal auditory deficit), or they have an FM deficit which the current study was unable to reveal. The small group sizes make it impossible to draw one or the other conclusion with any certainty. However, it is interesting that there was clearly greater variability in 2 Hz FM thresholds within the SLI group than with the control group, even after 'illegitimate' thresholds had been discarded, which was not due to outliers. There was also a tendency toward poorer performance within the SLI group, such that half the SLI group had higher thresholds than the highest threshold in the control group. This pattern was not seen in the 240 Hz FM condition. A tentative conclusion is therefore that there is a difference in the pattern of performance between the groups, even if it is subtle and manifested in the shape rather than the mean of the distribution. This finding merits further exploration, ideally using a more child-friendly task which will yield a greater proportion of reliable data.

It should also be noted that the two children described as PLI both, had much higher thresholds for 2 Hz FM than either children with SLI or control children; it may be that they have a genuine insensitivity to FM, or it may be that they are particularly vulnerable to attentional factors. The fact that their performance on 240 Hz FM was within the range of the other children's, makes the former possibility seem the more likely. However, it is impossible to generalise from a sample size of two!

Apart from comparing the slow rate FM sensitivity in children with SLI versus children with normally developing language, another purpose of the current study was to confirm the relationship between slow rate FM and phonological skill reported by Witton, Talcott and colleagues (Witton et al.,1998, 2002; Talcott et al., 2000). If sensitivity to FM is important to phonological development, this relationship should be manifest regardless of the language status of the individual. The correlational analysis revealed a trend for 2 Hz FM (but not 240 Hz FM) thresholds to correlate with language tests, particularly those with a phonological component, but not with nonverbal ability. However, due to the small number of thresholds which were retained and could be used for analysis, none of the correlations reached significance.

A median split procedure proved to be a more sensitive probe, and revealed that for all three of the phonology measures (non-word reading, non-word repetition, and phonological discrimination), children whose phonology scores were below the group's median were significantly less sensitive to 2 Hz FM than children whose phonology scores were above the median. This suggests that there does exist an interesting, though subtle, association between sensitivity to 2 Hz FM and phonology. Once again, though, it is hard to draw any firm conclusions with such a small sample size.

It is widely accepted that many children with SLI have phonological deficits, even when speech production is normal. The breadth of these deficits was recently emphasised in a study by Leitao, Hogben and Fletcher (1997). They examined phonological segmentation, blending and deletion tasks, as well as nonword repetition and rapid naming, in carefully defined groups of children with language impairment, speech impairment, or both. The results were unequivocal and showed that a language impairment, whether accompanied by speech problems or not, resulted in poor performance across the range of phonological tasks, relative to control children. Whether or not these deficits are causally related to their wider language difficulties is not a question which is addressed by the current study, but the question of whether the phonological deficits stem from a lower-level non-verbal FM perception deficit is very much of interest.

The phonological tasks used in the current study all tap different aspects of phonological processing, from decoding in nonword reading, to phonological working memory in nonword repetition, to speech perception in phonological discrimination. The three tasks were reasonably highly intercorrelated (in the region of r = .5) in the current sample, with the correlation between nonword repetition and phonological discrimination being slightly lower.

The only way to read nonwords is by decoding grapheme-phoneme correspondences and this necessarily engages phonological processes. Nonword reading is the measure which most consistently correlates robustly with 2 Hz FM thresholds in studies with adults with dyslexia as well as normally-reading adults and children. The reported correlation coefficients range from .47 (Witton et al., 2002) to .80 (Talcott et al., 2000), which contrasts with the .28 coefficient estimated in the current study. This may well be due to the floor effects observed in the SLI group: only one child from this group was able to read more than one nonword out of the twenty in the list, whereas the worst score in the control group was 13 out of 20. Nonword reading is a useful estimate of phonological decoding in normal reading development as well as dyslexia (Snowling, 2000) and it is clear that the current group of children with SLI is very poor at this. However, it is so far beyond the reach of most of these children that it does not give very much information about the range of phonological decoding skill within the group; and range within a variable is necessary for calculating correlations. Nonetheless, children who were poor nonword readers also tended to be poor 2 Hz FM detectors, and those who were good nonword readers were good 2 Hz FM detectors. Given that the 'poor nonword reading' group corresponded very closely to the SLI group, it is unclear why the group differences emerged in one grouping but not the other.

Nonword repetition has been extensively studied in children with language impairment, and has been found to have high heritability (Bishop, North & Donlan, 1996; Bishop et al., 1999) and to discriminate between language-impaired and non language-impaired children with a high degree of accuracy (Dollaghan & Campbell, 1998; Ellis Weismer et al., 2000). In normal development, it has a strong causal influence on vocabulary acquisition in both young children (Gathercole, Willis, Emslie & Baddeley, 1992) and adolescents (Gathercole, Service, Hitch, Adams & Martin, 1999), and is also associated with grammatical complexity in young children's speech (Adams & Gathercole, 1995). Similar associations occur in language impairment, such that children with SLI who score highly on a non-word repetition test perform significantly better than those who do poorly on nonword repetition on a wide range of language measures (Botting & Conti-Ramsden, 2001). The nonword repetition paradigm is usually discussed in terms of phonological working memory; early findings that children with language impairment were poor at nonword repetition were interpreted directly as indicating a limitation in the phonological loop component of working memory (Gathercole & Baddeley, 1990). However, phonological analysis, articulatory output processes and long-term lexical knowledge may also contribute to performance of this task (Snowling, Chiat & Hulme, 1991). In the current study, there were indications that nonword repetition, like nonword reading, was associated with sensitivity to 2 Hz FM. It is possible that the phonological working memory demands of the task were implicated in this association: this idea would be supported by finding a similar relationship between the auditory digit span task (which also places high demands on phonological working memory) and 2 Hz FM detection. Although this pattern of results was not found in the current study, it is interesting to note that it was found in a subsequent study (see Chapter 4). However, it also possible that the association between nonword repetition and 2 Hz FM sensitivity found in the current study, could be mediated by the phonological analysis or speech perception component of the nonword repetition task, since both this and FM detection require lower-level auditory analysis. On the other hand, the low intercorrelation between phonological discrimination and nonword repetition scores in this sample argues against this suggestion.

Of the three phonological tasks used in this study, the phonological discrimination task showed the strongest relationship with 2 Hz FM thresholds, so that even with age partialled out the correlation coefficient between the two was .44. This task was originally developed to examine speech perception in children with verbal dyspraxia (Bridgeman & Snowling, 1988), who were found to have considerably more difficulty with discriminating the order of segments within a sequence (e.g. lest/lets) than the segments themselves (let/less). A direct non-verbal auditory analogue of this task might be more similar to the Auditory Repetition Task than to FM detection; nonetheless, FM is an integral part of accurate speech perception, particularly of consonants, so it is not surprising that performance on the two tasks should be related.

Arguably, given that phonological discrimination is the most low-level task of the three, it is to be expected that it will have the strongest association with FM detection.

In conclusion, the results from the current study suggest that children with SLI may be less sensitive to a slow rate of FM than typically-developing children. They also indicate that sensitivity to a slow rate of FM may relate to performance on phonological tasks, regardless of language status. However, sensitivity to FM does not appear to relate to coherent motion sensitivity, at least not independently of age, as would be predicted by the magnocellular hypothesis. This pattern of results is consistent with the hypothesis that there is a deficit in the detection of at least auditory dynamic stimuli in children with SLI, and that this deficit in the auditory domain may underlie the phonological deficits seen in this population. However, though suggestive the results are not conclusive. This is largely due to the loss of a large amount of data through the use of a psychophysical procedure that is not suitable for use with young children, who are prone to inattention. It is important to confirm the current pattern of results with a psychophysical task that will maintain children's attention and yield a greater proportion of reliable threshold estimates.

Chapter 4: Frequency Modulation at 2 Hz, 20 Hz, and 240 Hz

Introduction

The experiment reported in chapter 3 suggested that there may be an insensitivity to slow rates of frequency modulation in children with SLI, and in addition that sensitivity to FM may correlate with performance on tests of phonological ability, regardless of the individual's language status. However, the experimental paradigm used in that study proved to be unsuitable for obtaining reliable psychoacoustic thresholds in young children, as it had a high memory load and was not sufficiently motivating. Much of the data had to be discarded as a result. It was important, therefore, to clarify whether the trends identified in chapter 3 could be confirmed using a method that would yield a higher proportion of reliable data.

A task was developed which was designed specifically to be more child-friendly. The 2-alternative forced-choice paradigm was preserved in the context of a computer game, referred to as the Dinosaur Game (see Figure 4.1). An alternative to 2-AFC, which would reduce the memory load, would be to decrease the number of tones per trial to one, and to ask the child to state whether an FM was present or not (yes/no task). However, this would have introduced an unacceptable risk of response bias since each individual has potentially different criteria for deciding that a stimulus is present or absent; a threshold calculated on this basis may reflect decision levels rather than, or as well as, detection levels. Forced-choice paradigms avoid this difficulty by eliminating the decision about whether the stimulus is present or absent. Instead of changing from a 2-AFC to a yes/no paradigm, the lightening of the memory load, arguably the main difficulty for children with the previous task, was achieved by associating each tone with a picture on the computer screen. A red and a yellow disc in the centre of the screen were each adjacent to a picture of a dinosaur. The dinosaur on the left was associated with the first tone, and would jump to touch its circle simultaneously with the presentation of the first tone, while the second tone was associated with the dinosaur on the right. The child was required to touch the circle associated with the target (FM) tone, the order of FM and pure tones being always randomised.

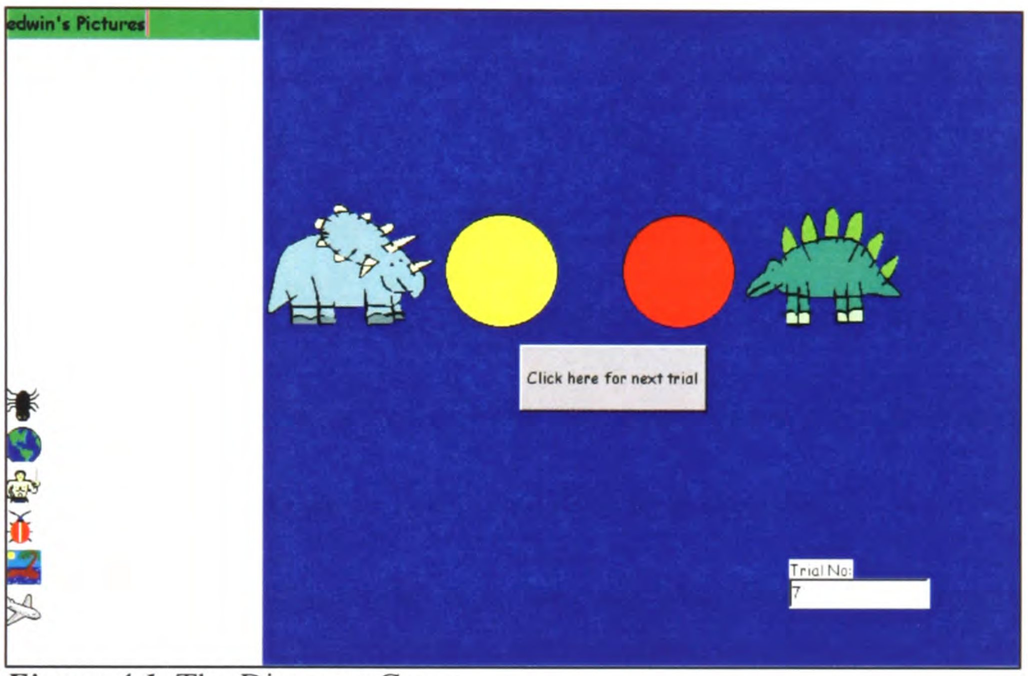


Figure 4.1 The Dinosaur Game

The second major modification to the task was introduced to increase motivation, and hence maintain attention, by rewarding correct responses. In infant psychoacoustics, using a head-turn procedure, reinforcement has been shown to be a critical variable: not only do infants display attentive behaviour - i.e. turning their head towards the sound - up to 30% more often when a reinforcer is present than when it is absent (Trehub, Schneider & Bull, 1981; Moore, Wilson & Thompson, 1977), but detection thresholds are also lower when a suitable reinforcer is used (Werner & Feeney, 1990). In fact, Wightman and Allen (1992) have even argued that, based on simulations which attempt to model the difference between child and adult detection thresholds by examining the effect of different rates of guessing:

> we cannot reject the hypothesis that a guessing rate of 50% can account for the entire adult-child difference in detection performance (p 132).

Using reinforcement to keep attention focused must clearly be an important part of any new task designed to be used with children. In the dinosaur game, each correct response was rewarded by the appearance of a colourful small icon on the left-hand side of the screen; as the game progressed a range of different icons were presented.

Another important modification to the task to increase attentiveness was the removal of pacing: rather than each trial following automatically from the response to the previous trial, each trial was initiated by the experimenter. This meant that the stimuli were presented only when the child's attention was (or at least appeared to be) on task, and decreased the chance of 'losing' trials to inattention.

A fourth major change to the task was the adoption of an adaptive staircase method rather than the method of constant stimuli. It could be argued that an adaptive staircase is more vulnerable to inattention, because each stimulus presentation is dependent on the response to the previous stimulus: a child who responds incorrectly because he or she is staring out the window will thereby elicit easier and easier stimuli whose levels will not be reflective of the child's actual sensory sensitivity. This is not a risk with the method of constant stimuli, because the stimulus level is independent of the child's responses. On the other hand, the method of constant stimuli relies heavily on an accurate approximation of the threshold level before the full psychometric function is obtained; this becomes more difficult to do as between-subject variability increases (as might be expected with groups of young children). A further advantage that the adaptive staircase has over the method of constant stimuli is that it concentrates trials in the vicinity of the threshold; this makes it efficient and a threshold estimate can be obtained with a relatively small number of trials. Finally, the method of constant stimuli is not a guarantee for maintaining attention and motivation as was observed in chapter 3 of this thesis: it can be very de-motivating for a child to make an incorrect response because the stimulus is difficult to detect, and then find that the following trial turns out to be even more difficult instead of easing them back into the task as would occur in an adaptive staircase. Taken altogether, these considerations justify the use of an adaptive staircase procedure rather than the method of constant stimuli for the current experiment. However, it should be noted that at least in infant studies, final threshold estimates are very similar whether an adaptive procedure or the method of constant stimuli is used (Werner, 1992).

Rationale for the current study

It was anticipated that embedding a standard 2-AFC paradigm into the Dinosaur Game, which reduced memory load and used reinforcement, pacing, and an adaptive staircase procedure to increase attention and motivation, would succeed in obtaining reliable threshold estimates for FM detection in children. These could then clarify whether children with SLI were indeed less sensitive to FM in tones, and whether FM sensitivity was related to performance on phonological tasks.

Following the methodological differences to the experiment reported in chapter 3, the only further change in the current experiment was the inclusion of a 20 Hz FM condition, in addition to the 2 Hz and 240 Hz conditions. The 20 Hz modulation rate has yielded interesting results before: adults dyslexic listeners have been found to have reduced sensitivity to a tone amplitude modulated at a rate of 20 Hz (Menell et al., 1999). Further, Witton et al. (2002) reported that detection thresholds for 20 Hz AM predicted independent variance for nonword reading ability, at a similar level to 2 Hz FM. If the critical variable is the rate of change, it is plausible that 20 Hz FM might produce similar results/

An additional point to consider is how different rates of modulation relate to speech perception, which is the route through which FM and AM deficits are hypothesised to affect phonological development in both dyslexia and SLI. Since the term 'hertz' refers to cycles per second, a 2 Hz rate of modulation means a complete cycle of frequency (or amplitude) change twice in every second; the window of time in which the change is taking place is therefore 500 ms. In natural speech, 500 ms roughly equates to the length of a syllable. 20 Hz, by contrast, involves change in a 50 ms window, which is closer to the time-frame of individual phonemes. One might expect on the basis of this that sensitivity to 2 Hz may be related to perception of suprasegmental information, such as syllabic stress, whereas 20 Hz may be more strongly related to perception of segmental information, and phoneme discrimination.

The experimental predictions of the current study are that children with language impairment, in contrast to age- and IQ-matched controls, will show decreased sensitivity to 2 Hz and 20 Hz FM, as these require the tracking of dynamic changes in the stimulus, but not to 240 Hz FM, which is detected by spectral mechanisms. Moreover, 2 Hz and 20 Hz, but not 240 Hz, FM sensitivity is predicted to correlate significantly with performance on tasks tapping various aspects of phonological ability (nonword reading, nonword repetition, phonological discrimination). A tentative prediction is that of these correlations, the one between 20 Hz FM and phonological discrimination will be the strongest, as 20 Hz is a rate of modulation which could plausibly directly affect the perception of phonemes.

Method

Participants

The same children participated in this study as in the previous two studies, except for one control child and one child with SLI who had moved out of the region. This study took place approximately 6 months after the experiment reported in chapter 2, and 12 months after the experiment reported in chapter 3. Table 4.1 provides means and standard deviations for age and scores on Raven's matrices, the criteria on which groups were matched.

Mean (SD) *min - max*	**SLI** ***n* = 11**	**PLI** ***n* = 4**	**SLI-Control** ***n* = 12**	**PLI-Control** ***n* = 3**
Age (years:months)	10;4 (1:10) 7;6 - 13;0	9;4 (0;11) 8;0 - 9;8	10:5 (1;9) 7:7 - 12;9	9;2 (0;10) 8;2 - 9;6
Raven's Matrices	101.82 (11.16) 86 - 125	115.50 (9.15) 103 - 125	100 (8.08) 88 - 114	121.33 (6.35) 114 - 125

Table 4.1: Group profiles, in terms of age and nonverbal ability.

Stimuli

Three modulation rates were tested: 2 Hz, 20 Hz, and 240 Hz. The experimental conditions were those testing slow rates of FM - 2 Hz and 20 Hz - as these reflect temporal processing, and their perception requires the tracking of frequency changes of the stimulus. The control condition was that testing the fast rate of FM, 240 Hz, which is detected by the use of spectral mechanisms and is not a measure of temporal processing.

For each rate of FM a set of 99 frequency modulated tones were created on a Tucker Davies Technologies signal generator (limit of 99 set by psychophysics software): these began at a modulation depth of 0 (that is, did not vary at all from the carrier frequency of 1000 Hz), and increased incrementally. In the 2 Hz FM condition, the step-size was 0.30 Hz, which allowed a range from 0 Hz to 30 Hz modulation depth. In the 20 Hz FM and 240 Hz FM conditions, the step-size was 0.50 Hz, which allowed a range of 0 Hz to 49.50 Hz. The step-sizes and consequent ranges were chosen to cover the range seen in previous experiments (Expt 1, Witton et al.,1998; Bishop et al.,1999), and to be sufficiently fine-grained to differentiate between low thresholds.

Procedure

The FM tones were presented in the context of the 'Dinosaur Game', in which two dinosaurs appear on either side of the computer screen with a large coloured disc by their head (see introduction to this chapter). In each trial, the child heard two tones over Sennheiser HD45 headphones, one of which was frequency modulated, and one of which was a pure tone at 1000 Hz . The interstimulus interval was 500 ms, and tone duration was 1 second. Each tone was associated with one of the coloured discs on the screen pulsing, and the child was required to touch the disc associated with the target (FM) tone. When the child made a correct response, he or she was rewarded with a little picture on the left side of the screen; these prize pictures built up over the course of the game. An incorrect response elicited a sighing sound and a black X on the screen.

Targets in the initial trials had very large modulation depths, and the task proceeded with an adaptive parameter estimation by sequential tracking (PEST) procedure (Taylor & Creelman, 1967): large step-sizes in the beginning, decreasing throughout the course of the run until 10 reversals (change from correct to incorrect response) were completed, or after 80 trials, whichever came first. A threshold was then calculated as the average of the modulation depth at all the reversal points after the first 4. Two threshold estimates were calculated for each child for each of the three conditions (2 Hz, 20 Hz and 240 Hz); six threshold estimates took roughly 30 minutes to complete

All testing was carried out in a quiet room, either at school or, in one case, at the child's home. The Dinosaur Game was presented on a Gateway Solo laptop computer, attached to a touch-screen monitor. Children's responses on touching the coloured disc in each trial were therefore automatically recorded. Due to equipment failure, a small number of children were tested without a touch-screen; in these cases the children still touched the coloured disc to respond, but the response was only recorded when the experimenter clicked on the disc with the mouse.

Results

Two threshold estimates were successfully obtained per child for each of the three modulation rates (2, 20 and 240 Hz FM). A 4 (group) x 2 (threshold estimate) x 3 (FM rate) analysis of variance confirmed that there was no significant main effect of threshold [F (1,25) = 1.51, p > .05], nor any interactions. The first and second thresholds were therefore averaged. The distributions were normalised by $\log_{10}$ transforming the averaged threshold estimates, expressed in terms of the modulation index (which equals the modulation depth in Hz divided by the modulation rate in Hz).

2 Hz FM: Group comparisons for SLI

Inspection of group thresholds in Figure 4.2 reveals that the SLI group performed at a similar level to the control group on the 2 Hz FM detection task. This is contrary to the experimental hypothesis, which predicted that the SLI group would have significantly higher FM detection thresholds than the control group in the 2 Hz condition.

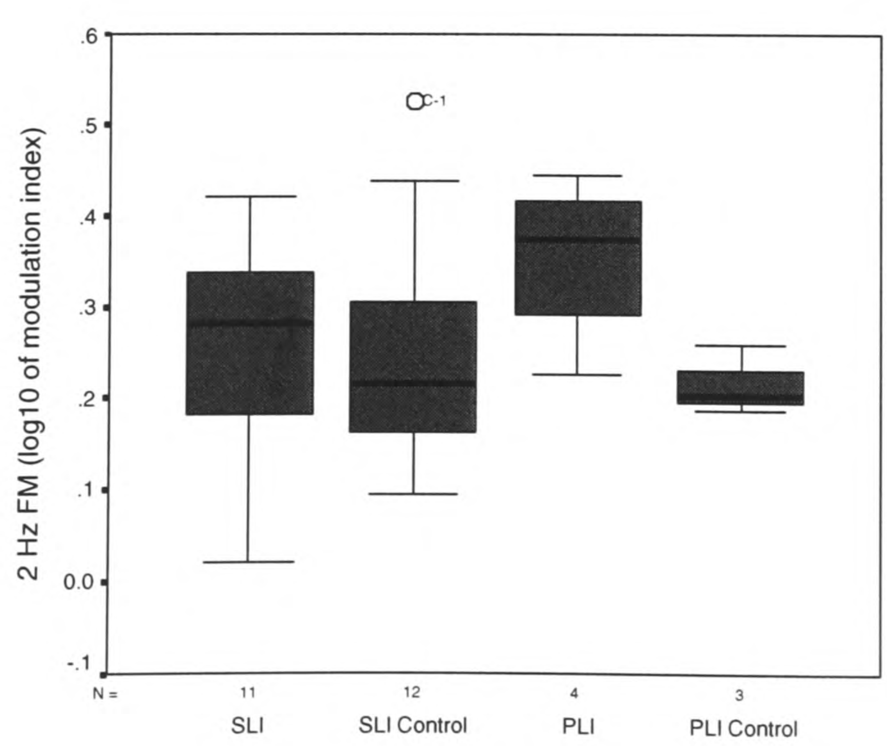


Figure 4.2: Frequency modulation detection thresholds for 2 Hz modulation rate. Boxplots indicate the median, quartiles and extremes of the distribution.

The lack of a group difference was confirmed by an independent samples *t*-test, which showed that the mean threshold estimates obtained for the SLI group were not significantly different from those of the SLI Control group (Table 4.1).

Group	*n*	*M*	*SD*	*t*	*df*	*p*
SLI	11	0.25	0.13	0.04	21	.97
SLI-Control	12	0.25	0.13			

Table 4.1: 2 Hz FM detection means for SLI and SLI-Control groups, and independent-samples *t*-test.

2 Hz FM: PLI

Figure 4.2 shows that there was little overlap in performance between the PLI group and either of the control groups; this is consistent with the finding in Experiment 2 of higher FM detection thresholds for the PLI group. The mean threshold value for the PLI group was $M = 0.35$ ($SD = 0.09$), while that for the PLI control group was $M = 0.22$ ($SD = 0.04$). Due to the small group size, no statistical analysis was carried out.

20 Hz FM: Group comparisons for SLI

The boxplot in Figure 4.3, with group thresholds for 20 Hz FM, shows highly overlapping distributions across all groups, whether language impaired or control.

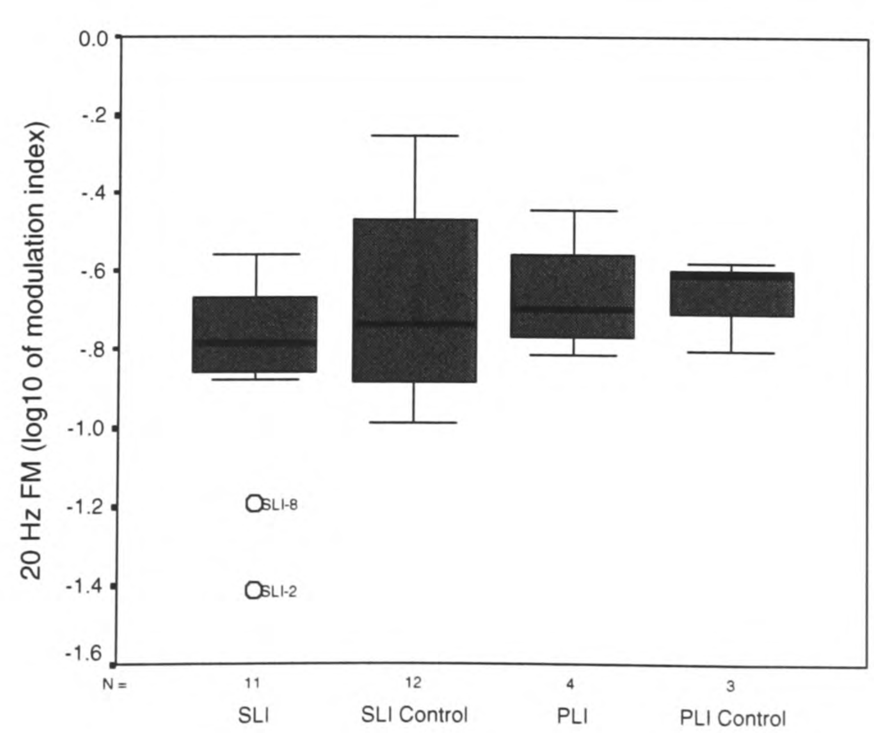


Figure 4.3: Frequency modulation detection thresholds for 20 Hz modulation rate.

An independent samples *t*-test confirmed that the SLI and SLI Control groups did not differ significantly in mean detection thresholds for this rate of FM (Table 4.2).

Group	*n*	*M*	*SD*	*t*	*df*	*p*
SLI	11	-0.84	0.26	-1.60	21	.12
SLI-Control	12	-0.67	0.25			

Table 4.2: 2 Hz FM detection means for SLI and SLI-Control groups, and independent-samples *t*-test.

20 Hz FM: PLI

Unlike the case for 2 Hz FM, the PLI group had very similar thresholds to both SLI and control groups in the 20 Hz FM condition. The mean threshold for the PLI group was M = -0.66 (SD = 0.16), while that for the PLI Control group was M = -0.67 (SD = 0.12), values which were a little higher than the mean for the SLI group, and virtually identical to the mean for the SLI Control group. No statistical analyses were carried out because of the small group sizes, but it seems clear that the PLI thresholds did not differ from those of controls.

240 Hz FM: Group comparisons for SLI

An unexpected feature of the data for the 240 Hz FM condition (depicted in Figure 4.4) was that the SLI Control group appeared to have overall higher thresholds than the SLI group. Though there was substantial overlap between the distributions, the median for the SLI Control group was higher than 75% of the SLI group.

An independent samples *t*-test, however, showed that the apparent group differences were not significant, and that the mean detection thresholds were equivalent for the SLI and SLI Control groups (Table 4.3).

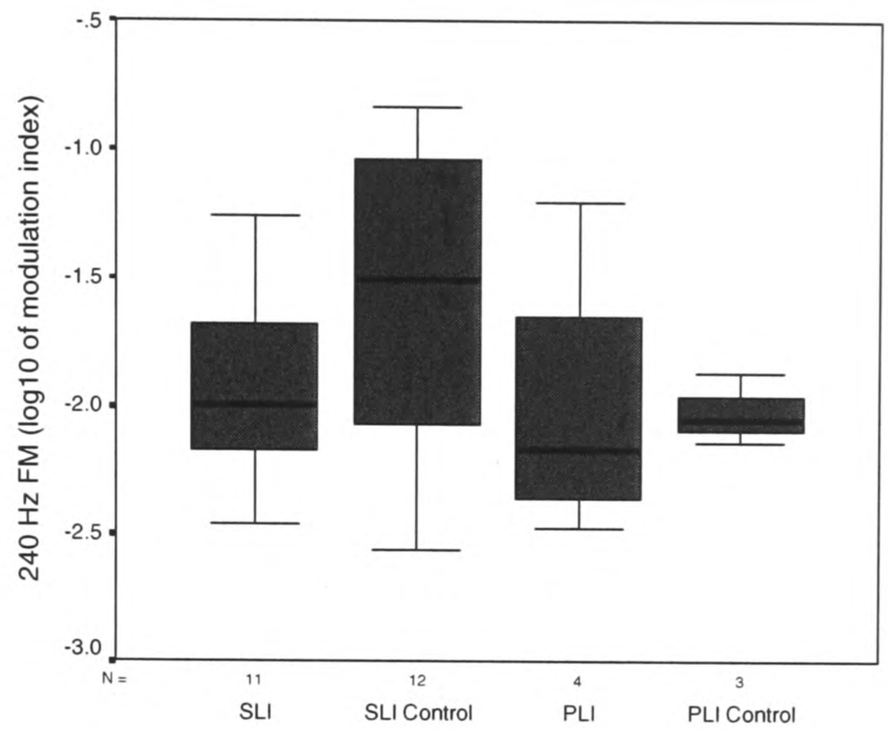


Figure 4.4: Frequency modulation detection thresholds for 240 Hz modulation rate.

Group	***n***	***M***	***SD***	***t***	***df***	***p***
SLI	11	-1.92	0.39	-1.59	18.48	.13
SLI-Control	12	-1.58	0.63			

Table 4.3: 240 Hz FM detection means for SLI and SLI-Control groups, and independent-samples *t*-test.

240 Hz FM: PLI

The performance of the PLI group on 240 Hz FM detection was very similar to that of both the PLI control group and the SLI group. The mean of the detection thresholds for the PLI group was M = -2.00 (SD = 0.56), while that for the PLI control group was M = -2.02 (SD = 0.14). As before, statistical comparisons were not carried out because of the small group sizes, but the thresholds in the PLI group were clearly comparable to those in the other groups.

Age effects

Age did not correlate significantly with detection thresholds for either 2 Hz FM [r_s (29) = -.18, $p > .05$] or 20 Hz FM [r_s (29) = -.25, $p > .05$]. However, age did correlate significantly with detection thresholds for 240 Hz FM [r_s (29) = -.37, p <

.05]. This is a different pattern to that observed in chapter 3, in which slow but not fast rate FM correlated strongly with age.

2 Hz, 20 Hz and 240 Hz FM

Correlation coefficients were calculated for the relationships between detection thresholds on the three rates of FM. 2 Hz and 20 Hz FM were found to be highly inter-correlated [r_s (29) = .66, $p < .001$], which is consistent with the idea that both rates are detected based on analysis of the temporal properties of the stimulus. On the other hand, 240 Hz FM did not correlate significantly with either 2 Hz [r_s (29) = .18, $p > .05$] or 20 Hz FM [r_s (29) = .17, $p > .05$]. This is again consistent with the idea that the fast rate of FM is detected using a different (non-temporal) auditory mechanism to that used for slow rates of FM.

Frequency modulation and phonology: Correlational analysis

A non-parametric correlational analysis exploring the relationship between FM detection and tasks which tap different aspects of phonology, as well as of more general language and nonverbal ability, is presented in Table 4.4. Note that data on the phonological tasks were obtained during testing for the experiment reported in chapter 3.

	2 Hz FM *n = 30*	**20 Hz FM** *n = 30*	**240 Hz FM** *n = 30*
Raven's Matrices	.01	.06	.04
BPVS	**-.39**	.10	.13
Nonword Reading	-.08	.05	.17
Nonword Repetition	-.26	-.19	.14
Phonological Discrimination*	-.31	.04	-.08
Sentence Recall	-.04	.08	-.11
Digit Span*	-.21	.18	.22

Table 4.4: Spearman's correlations between FM detection thresholds and verbal & nonverbal measures. Bold indicates significance at the .05 level. *Age partialled out of correlation

The only significant correlation was that between 2 Hz FM detection and vocabulary knowledge (BPVS); this became non-significant when a Bonferroni correction was applied to compensate for the large number of correlations calculated. It could be argued that there was a trend for 2 Hz FM detection thresholds to correlate with nonword repetition, and particularly phonological discrimination scores; the same could not be said for 20 Hz FM thresholds. This was not in line with the experimental predictions. However, as predicted, 240 Hz FM did not correlate with any of the measures, nor did any of the FM conditions correlate with performance on the Raven's Matrices.

The median split procedure used in chapter 3 may clarify the strength of the relationship between sensitivity to the slowest rate of FM (2 Hz) and performance on the nonword repetition and phonological discrimination tasks.

Median split: Nonword repetition and phonological discrimination

Median performance for nonword repetition was an age-standardised score of 60. Examination of the boxplots (Figure 4.5) suggests substantial overlap in 2 Hz FM detection thresholds between children who performed below and above the median score on the nonword repetition task. This was confirmed by an independent samples t-test [t (28) = 0.16, $p > .05$].

The situation was a little less clear in the case of phonological discrimination (median score of 52 out of 60, raw score) as the group of children performing above the median had a much tighter distribution of 2 Hz FM detection thresholds, which had relatively little overlap with that of the group performing below the median. Nonetheless, an independent samples t-test did not show a significant group difference test [t (28) = 1.78, $p > .05$]. It should be noted that age and Raven's matrices scores did not differ significantly between the groups for either nonword repetition or phonological discrimination median splits. The groups created by the median split procedure for both of these phonological tasks also performed similarly in the 20 Hz and 240 Hz FM conditions.

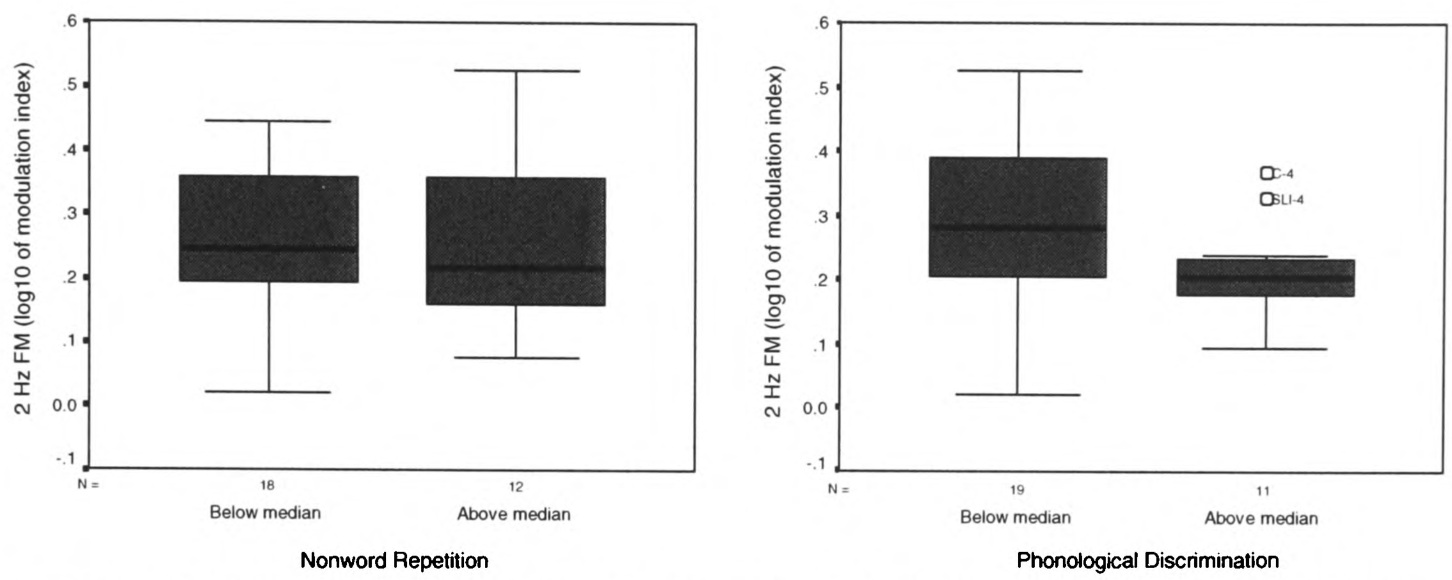


Figure 4.5 2 Hz FM detection thresholds for groups derived from nonword repetition (left) and phonological discrimination (right) median split. Groups scoring below the median are on the left side of each graph; those scoring above the median are on the right side.

There was no trend for a correlation between nonword reading and 2 Hz FM detection; however, as the results of chapter 3 were strongly suggestive of such a correlation, a median split procedure was carried out with the current data. The median performance on this task, including data from all participants, was 91.5. Children performing below the median were not significantly less sensitive to 2 Hz FM than children performing above the median test [t (28) = 1.45, $p > .05$]. However, it is interesting to note that the variability in performance was much smaller for the 'above median' than the 'below median' group (Figure 4.6). This is a similar pattern to that observed for phonological discrimination, but not nonword repetition. As before, the two groups derived from the nonword reading median split did not differ significantly in age or scores on Raven's matrices.

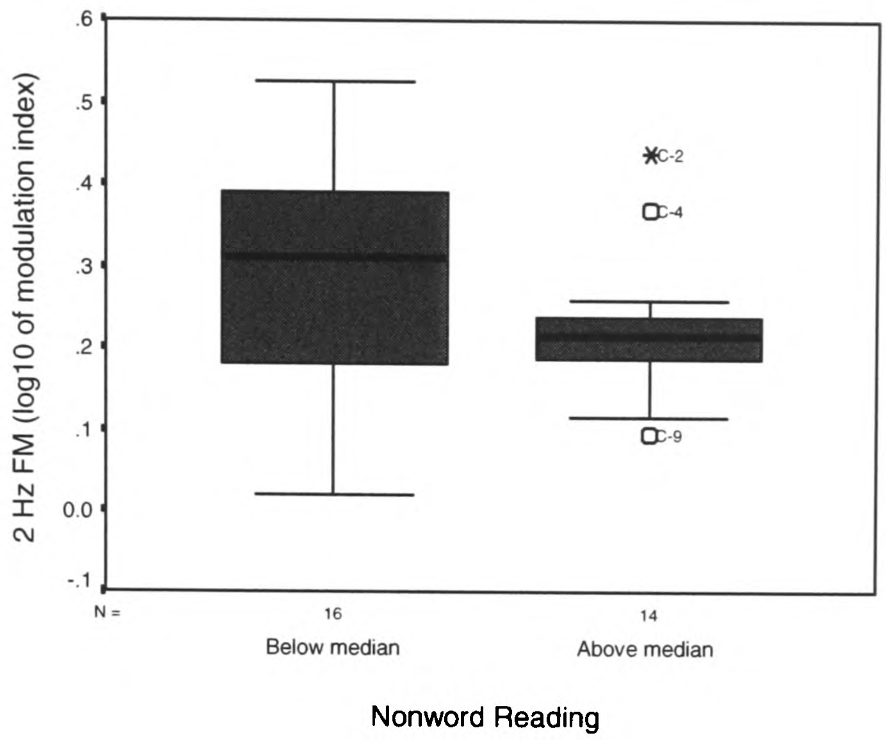


Figure 4.6: 2 Hz FM detection thresholds for groups derived from nonword reading median split. The group scoring below the median is on the left side of the graph; the group scoring above the median is on the right side.

Comparing FM thresholds from chapters 3 and 4

FM detection thresholds were compared for the studies reported in chapters 3 and 4: mean threshold values, reported in Hz, are presented in Table 4.5. Mean thresholds were clearly lower for both 2 and 240 Hz FM in the current study than they were in the previous study. Since the same children participated in both studies, the lower thresholds must be explained either by a developmental effect - since the children were a year older in the second study than they were in the first - or by a practice effect, or by the methodological differences between the two studies.

Mean (SD) *n*	**2 Hz**	**20 Hz**	**240 Hz**
Chapter 3	10.63 (8.62) *n = 14*	-	33.29 (79.2) *n = 23*
Chapter 4	3.77 (1.09) *n = 30*	4.28 (2.27) *n = 30*	7.56 (9.35) *n = 30*

Table 4.5: Mean detection threshold values (depth of modulation reported in Hz) for 2, 20 and 240 Hz rates of modulation, for the experiments reported in chapter 3 and chapter 4 of this thesis.

Despite the difference in the overall level of detection thresholds, the results suggest reasonable stability in FM sensitivity over the course of the two studies: there was a strong correlation between the two sets of 2 Hz FM thresholds [r (14) = .60, $p <$ .05], and a slightly weaker correlation between the two sets of 240 Hz FM thresholds [r (22) = .40, p = .06].

It is interesting to note that the 20 Hz FM thresholds from the second study correlated well with the 2 Hz FM thresholds from the first study [r (13) = .46, $p >$ .05], as might be expected if their perception relies on the same temporal processing mechanisms. It is less obvious why there was also a noticeable, though weaker, correlation between 20 Hz FM and 240 Hz FM [r (22) = .36, $p >$ .05], since different mechanisms are believed to underlie the perception of these rates of FM.

Frequency modulation and motion coherence sensitivity

According to the predictions of the magnocellular hypothesis, sensitivity to dynamic stimuli should cross sensory domains: detection thresholds to slow rates of FM (2 and 20 Hz) should therefore correlate with detection thresholds for coherent motion stimuli. Detection of fast rates of FM (240 Hz) and coherent form, by contrast, should not be related to detection of dynamic stimuli. As the same children participated in the current study and in the coherent motion study, it was possible to test these predictions directly; however, it should be remembered that the auditory thresholds were obtained approximately 6 months after the visual thresholds.

The correlation between 2 Hz FM and coherent motion was far weaker than expected [r_s (29) = .13, $p >$ .05]. The correlation between 20 Hz FM and coherent motion, on the other hand, was significant and thus in line with the experimental predictions [r_s (29) = .37, $p <$ .05]. Unlike the case in chapter 3, this correlation was not much changed when age was partialled out of the calculation, although it became non-significant [pr (28) = .31, $p > .05$]. As predicted, neither 240 Hz FM nor coherent form thresholds correlated significantly with thresholds for any of the dynamic stimuli.

Discussion

The Dinosaur Game was successful in obtaining reliable detection thresholds for the three rates of FM tested: 2, 20 and 240 Hz. These correlated well with the thresholds obtained a year earlier with the same children, suggesting that both tasks provided threshold estimates which reflected sensory sensitivity rather than any task-specific factors. However, in comparison to the task used in the first study, the current task yielded a much higher proportion of data which could be used for statistical analysis. The conclusions drawn from this data therefore over-ride any tentative conclusions drawn from the earlier data set.

For none of the three rates of modulation were children with language impairment found to be less sensitive to frequency modulation in a tone than children with typically-developing language. This does not support the main experimental hypothesis that children with language impairment would show a deficit in processing the temporal elements of an auditory stimulus.

The second experimental hypothesis was that regardless of an individual's language status, his or her sensitivity to slow rates of FM should correlate with tasks which tap phonological ability. Little support can be found for this hypothesis in the current data. The correlations between 2 Hz FM thresholds and nonword reading, nonword repetition and phonological discrimination were weak; a median split procedure was unable to uncover a more convincing relationship of the sort hinted at in chapter 3. The results for 20 Hz FM were even less positive, with none of the correlation coefficients reaching even .2. This is perhaps particularly surprising for 20 Hz FM and phonological discrimination, which were arguably the most directly analogous speech and non-speech perceptual tasks examined.

Finally, sensitivity to dynamic stimuli in the auditory domain does not appear to be strongly related to sensitivity to dynamic stimuli in the visual domain.

Taken altogether, the findings from the current study cannot support the claims of the magnocellular hypothesis in this group of children with language impairment. Had the results been positive, and the children with SLI found to have impaired detection of FM, it would have been strong evidence in favour of a shared mechanism underlying SLI and developmental dyslexia. As it is, the results suggest the reverse, and call into question the assumption increasingly pervading the literature that SLI and developmental dyslexia lie on a continuum of disordered language development.

Such a conclusion is perhaps surprising in view of the high prevalence of co-occurring oral language and literacy problems in many children, and prompts a closer examination of the nature of the relationship between the two types of problem in language impaired populations.

The relationship between oral language and literacy problems

A commonly held view is that language delay or impairment in pre-school metamorphoses into literacy problems in the school years. Such a view is partially espoused by Tallal, Allard, Miller & Curtiss (1997) in a study on the academic outcomes of language impaired children. They followed a group of specifically language impaired children over a period of 5 years, starting from diagnosis at age 4; each year the children were assessed across five academic domains (mathematics, spelling, decoding, reading vocabulary and comprehension). The language-impaired group showed significant deficits across all domains, including mathematics. Moreover, the gap in performance between the language-impaired and control groups increased with time; this was most striking in the reading measures, so it is argued that the deficits become more specific to reading with time. Similar patterns of performance were observed when comparing individuals rather than groups. The authors conclude that:

> ...at least for children with developmental language impairment, it may be primarily the *age* of the child that differentiates developmental language from developmental reading impairment...Thus, we may be observing the developmental course of a single deficit rather than two distinct syndromes. (pp 179-180)

Although this portrayal is appealing in its simplicity, a set of longitudinal studies which followed the same cohort from ages 4 to 16 suggests that the reality may be more complex. This cohort consisted of a group of 88 children identified with a language impairment at age four, who were classified according to nonverbal ability as SLI (language lagging behind cognitive ability) or general language delay (language delay consistent with cognitive level). The children were re-assessed at 5½ (Bishop & Edmundson, 1987) and also at 8½ (Bishop & Adams, 1990). It was found that children whose oral language difficulties had resolved by the age of 5½ (44% of the SLI group but only 11% of the general delay group) appeared to have normal literacy development. In contrast, those children whose oral language difficulties were unresolved at age 5½ had subsequently poor literacy development as well as persisting oral language problems. It is interesting that in these children reading comprehension lagged behind reading accuracy; that is, their poor reading comprehension was attributable to more general verbal problems. This is not consistent with the idea that oral language difficulties turn into literacy difficulties, as the two seem to either co-occur or disappear completely, at least at age 8.

However, the picture becomes even more complicated when the results from the same children at age 15 are considered, despite the fact that the classification of 'resolved' or 'persistent' SLI at 5 ½ continued to hold for the majority of children at

15 (Stothard, Snowling, Bishop, Chipchase & Kaplan, 1998). The persistent-SLI group now looked very similar to the general delay group in both linguistic and cognitive profile, with oral and written language skills well below their chronological age-matched peers. The resolved-SLI group had age-normal scores on vocabulary and comprehension tests; however, they exhibited a deficit in phonology, as assessed by a nonword repetition task, a sentence recall task, and spoonerisms (a test of phonological awareness, in which the initial consonants of a pair of words must be swapped: 'paddington bear' goes to 'baddington pear'). In surprising contrast to the findings at age 8, the reading accuracy for this group was now below age expectations, even for children whose reading accuracy had been normal at age 8. This effect was magnified for those children whose nonverbal IQ scores were below 100 (Snowling, Bishop & Stothard, 2000).

A subgroup of this cohort is particularly interesting with respect to the relationship between phonological skill and subsequent language and literacy development. Twelve children from the original sample were found to have isolated expressive phonological difficulties, in terms of the percentage of consonants pronounced correctly in elicited speech (note that a phonological awareness task was not carried out with this group; they may or may not have exhibited a phonological awareness deficit). Despite the well-established causal relationship between phonological awareness and reading development, these children had a particularly good literacy outcome aged 8 (Bishop & Adams, 1990), and were also reading at an age-appropriate level aged 15 (Snowling, Adams, Bishop & Stothard, 2001). However, when compared to age- and IQ-matched controls, their receptive phonology was found to be weak, and their reading – although normal – to be considerably poorer than what could be expected from their nonverbal ability. In fact, using discrepancy criteria, they could be classified as dyslexic.

Finally, in a direct comparison between a group of adolescents with dyslexia who did not have a history of oral language impairment, and the adolescents with SLI described in Stothard et al. (1998) and Snowling et al. (2000), the dyslexic group had comparable performance on oral language and phonological awareness tasks to the resolved-SLI group, but literacy skills at the level of the persistent-SLI group (Goulandris, Snowling & Walker, 2000).

The conclusions drawn from this set of studies suggest a different developmental trajectory for literacy difficulties in SLI and dyslexia, and emphasise the importance of the interaction of critical factors at different stages of reading development (Plaut, McClelland, Seidenberg & Patterson, 1996). Dyslexic children, according to this account, can be described as having a relatively selective phonological deficit which impairs decoding skills, a mechanism which is especially important at the early stages of reading. However, children with high nonverbal intelligence and good semantic and grammatical skills may well learn to use top-down processes which will compensate for poor reading accuracy and ensure good reading comprehension; these top-down processes will also bolster decoding for more complex words. Children with SLI, on the other hand, usually have language problems which extend beyond phonology. It is possible that a child will have sufficiently good phonological skills to learn to decode acceptably in the early stages of reading, but will begin to fall behind, in both accuracy and comprehension, when subsequent reading development begins to rely more on semantic and grammatical information.

The pattern emerges of different effects of an isolated phonological deficit (particularly in phonological awareness), and a broader language deficit which includes not only phonology but also lexical and syntactic skills. Catts (1993) describes the effects of these two profiles on the literacy skills of kindergarten children with speech and language impairments. Children who exhibit poor phonological awareness in kindergarten go on to have poor written word recognition in grades 1 and 2; children who have low scores on standardised language measures, on the other hand, go on to have poor reading comprehension.

The differentiation between phonology and comprehension may have a neurobiological substrate, as demonstrated by Leonard et al. (2001). Using volumetric MRI scans, Leonard and colleagues found that adults with dyslexia whose comprehension was good despite severe phonological deficits had extreme cerebral asymmetry and gyral duplications. In contrast, when phonological deficits were accompanied by poor oral and written comprehension skills, low cerebral volume was implicated.

The warning implicit in these findings against identifying SLI with dyslexia is also echoed in recent genetic studies which attempt to identify chromosomal loci associated with language or reading measures. Tests of single word and nonword reading, as well as phoneme segmentation and deletion, showed linkage at a locus on chromosome 18 (Fisher et al., 2002); on the other hand, receptive and expressive language assessed by the CELF-R and nonword repetition were associated with loci on chromosomes 16 and 19 (SLI Consortium, 2002).

The negative findings of the present study, which do not support the hypothesis of a common mechanism underlying dyslexia and SLI, are perhaps not so surprising after all. The broad assumption that that SLI and dyslexia are effectively more or less severe forms of the same language disorder does not stand. However, a narrower interpretation of this idea is still plausible.

A subgroup of children with both oral language and literacy problems

The converging evidence suggests that when the weight of an early childhood deficit is in phonological processing, and particularly phonological awareness, the consequences are largely restricted to word decoding and literacy (although note that isolated problems in articulation or expressive phonology do not necessarily impact negatively on literacy development, see for example Catts, 1993 and Bird, Bishop & Freeman, 1995); when the weight of the deficit includes lexical and syntactic processing the consequent language profile is one of poor comprehension, whether of written or oral language. It is possible that children who have both severe phonological and higher language deficits, that is, who have both literacy and language problems, may exhibit the auditory processing problems reported so inconsistently for dyslexia and SLI. The implication of this suggestion is that the inconsistency in the literature reporting auditory deficits is due to sampling factors: studies discussing SLI rarely include literacy measures, and studies discussing dyslexia even more rarely include oral language measures.

The idea of a particularly vulnerable subgroup of children, whose double hit of language and literacy deficits is accompanied by auditory processing deficits, is supported by the findings of Tallal (1980), who applied the auditory, visual, tactile and motor tasks described earlier in the context of SLI, to two groups of children with dyslexia. One group had concomitant oral language difficulties, while the other did not. The children with oral language difficulties performed poorly on both the temporal processing tasks and on a phonological decoding task (reading nonsense words), a similar profile to children with SLI. The group of dyslexic children without oral language difficulties performed as well as the control group on both the temporal processing tasks (in all modalities) and the phonological decoding task. A similar pattern was reported more recently by Heath et al (1999) and McArthur et al. (2000), who both found rapid auditory processing deficits in children with an oral language impairment in addition to a reading disability but not in children with either an oral language impairment or a reading disability. The distinctiveness of a subgroup of children with overlapping literacy and language deficits is supported by evidence from genetics: Bishop (2001) reported high heritability of literacy problems in a twin population, but only when the literacy difficulties co-occurred with poor nonword repetition, which was used as a marker for language impairment.

One possibility that might explain the negative findings in the current experiment, therefore, is that a perceptual deficit will only be demonstrable in children with SLI who have concomitant literacy difficulties. This study did not include extensive measures of literacy skill; however, it did include a nonword reading measure, which is regarded as a particularly sensitive indicator of reading difficulties (e.g. Bishop & Adams, 1990; also discussion in Snowling, 2000). According to this measure, only one of the children with language impairment had normal word decoding for his age, and his FM detection thresholds were indistinguishable from those for the rest of the SLI group. Furthermore, data relating to the reading skills of many of the children with SLI who participated in the current experiment, are reported in Briscoe, Bishop & Norbury (2001); their performance on measures of both word reading and reading comprehension is well below age-appropriate levels. Despite having a 'SLI + dyslexia' profile, these children with SLI do not appear to have an auditory deficit, which is not consistent with the 'double hit' hypothesis.

Independently of asking whether or not SLI and dyslexia share an underlying sensory mechanism, the current study also addresses the causal mechanism by which auditory deficits are hypothesised to affect language and literacy development: that is, the possible impact of an auditory deficit on phonological processing. The analyses including all participants were not encouraging in this respect, and threw some doubt on whether, even if group differences in FM sensitivity were apparent, these would be useful in explaining the linguistic differences between the groups. However, a closer examination of the data revealed a rather different pattern of performance in the language-impaired and control groups. While for the children with language impairment (both SLI and PLI) the correlation between 2 Hz FM and phonological discrimination stood virtually at nought ($r = .02$, $p = .95$), for the control children the correlation was significant ($r = -.54$, $p = .04$). This was particularly interesting given that it had been tentatively hypothesised that of the three phonological tasks used, phonological discrimination would be the most likely to correlate with FM. However, phonological discrimination also correlated highly with 240 Hz FM (the control condition) in the control group ($r = -.51$, $p = .05$). Even when the effects of nonverbal intelligence and/or age were partialled out, the correlation remained for both slow and fast FM in the control but not the SLI group. As far as this study can show, sensitivity to slow frequency modulation is not specifically related to phonological discrimination.

Null results do not allow bold conclusions; nonetheless, the lack of a correlation between FM detection and any of the phonological tasks examined within the SLI group is intriguing. If phonological deficits in SLI do not come from impaired auditory processing, where do they come from? It is interesting to speculate that perhaps the assumption of the pre-eminence of bottom-up processing, which informs any auditory deficit account, is inappropriate in SLI, whether or not it accurately describes normal development. It is plausible (although not unequivocally supported by the data) that in the normal course of events FM does play a role in phonological processing, but that in SLI a third factor - perhaps a top-down effect from impoverished linguistic representations - impacts on phonological development to such an extent that the 'normal' effect of FM can exert no more influence.

Chapter 5: The past tense in SLI - a phonological deficit?

Introduction

Chapters 3 and 4 of this thesis addressed the levels of auditory perception and phonology, and examined the relationship between them. The current chapter explores a higher level process, the perception of grammatical morphemes, and looks at how phonology might relate to it. Specifically, it looks at whether the phonological salience of grammatical morphemes affects children's sensitivity to them, and whether sensitivity to grammatical morphemes relates to phonological skills assessed in independent tasks, such as phonological discrimination.

Phonological accounts of morphosyntactic deficits in SLI

English-speaking children with SLI have particular difficulty with grammatical morphology, which is disproportionate to the general language impairment. Linguistic deficit accounts attribute this to a specific deficit in the grammar module. An alternative perspective suggests that the grammatical deficits are secondary to difficulties in the processing of phonology. As succinctly put by Joanisse and Seidenberg (1998):

> There is good evidence that SLI is associated with impairments in the processing of speech; that these impairments affect the development of phonological representations; and that degraded phonological representations are the proximal cause of deviant acquisition of morphology and syntax, by virtue of their roles in learning and working memory (p. 241).

This position follows on naturally from auditory deficit accounts of SLI; in fact a universal assumption of these accounts is that phonological deficits (caused by low-level auditory deficits) are responsible for the higher-level language problems which characterise SLI, including those of morphology and syntax. However, this is a major assumption in itself, and as linguistic accounts would have it, not necessarily justified. It is also important to remember that while the causal link between phonology and grammar is necessary to auditory deficit accounts, the link between auditory deficits and phonology is not necessary to phonological accounts. Underspecified phonological representations may be due other factors, such as impaired storage in phonological working memory (Gathercole & Baddeley, 1990), or even top-down influences from a limited vocabulary which does not require tightly specified word-forms (Charles-Luce & Luce, 1990).

Two accounts which take the position that morphosyntactic deficits in SLI are secondary to phonological deficits are the phonological theory of SLI (Chiat, 2001), and the surface hypothesis (Leonard, 1998). The phonological theory takes as its starting point the importance of the mapping process in early word learning (see overview in Chiat, 2001): the infant has to perceive a word form, identify its referent in the environment and map the one onto the other. The extraction of the word form from the speech stream and the extraction of the semantic referent from the visual or experiential scene do not occur independently of each other, but rather act as mutual bootstraps. An example of semantic bootstrapping proceeds from a 'joint attention episode' between an infant and adult (Moore & Dunham, 1995), which clarifies the semantics of *what* they are talking about, so that the child is able to search for the appropriate phonological form to associate with the object. If the child picks up a teddy bear and the adult says *teddy bear*, the child can be fairly confident that the speech sound *teddy bear* refers to the object in her hand. Conversely, in phonological bootstrapping, phonological cues, whether prosodic or segmental, can give information about appropriate semantic specification. The word *pretty* can be used to describe a quality shared by some flowers, people, scenes, or colours all of which present disparate experiences - it is the consistency of the phonological form *pretty* which acts as a pointer to the shared quality itself, and to the range of meaning of the word. A similar process takes place in the acquisition of functional, rather than just lexical, morphemes. A child acquiring English learns that the suffix *-ed* is a marker for the past tense, because the phonological form co-occurs consistently with contexts referring to the past. Finally, semantic and phonological cues are important for understanding syntactic structure. For example, understanding the semantic focus in a scene described by the sentence *I dropped the ball* versus *The ball fell* can give information about the argument structure of the verb and whether it requires an object or not.

The phonological theory of SLI suggests that early deficits in phonological processing, whatever their origin, will inevitably disrupt the word to referent mapping process with implications for both lexical and morphosyntactic development. The phonological theory makes predictions on two levels. The first level is concerned with the impact of phonology on semantics, and is based on the idea that "the less a word meaning can be cued by observation of scenes, the more the child must depend on phonological cues to discover it." (Chiat, 2001, p. 120) Hence concrete nouns should pose relatively little difficulty, while verbs should be more problematic. Mental state verbs, such as *think*, should be harder than verbs encoding visible events, such as *run*. Establishing the full range of meaning associated with a word, as in the example with *pretty* given earlier, should be difficult. Temporal terms, such as *yesterday*, should pose greater difficulty than terms dealing with immediate experience. That verbs are particularly problematic for children with SLI is well established (Leonard, 1998); as yet, there is little data available to test the more fine-grained predictions of the phonological theory about levels of difficulty within verbs.

The second level of predictions is that, within the semantic categories outlined above, forms which are phonologically strong should be more robust than those which are weak. Open class lexical items will therefore be more easily learnt and maintained than closed class function words and grammatical inflections. The greater the phonological salience, the more robust the morpheme. However, it is an important part of the phonological theory that phonological salience alone cannot account for the pattern of deficits in SLI; it must interact with the semantic and syntactic complexity of words which rely on phonological cues to disambiguate their meaning in the mapping process. An example given by Chiat (2001) is that according to the phonological theory, *nose* should be less problematic than *bees* which in turn should be less problematic than *bee's*, despite the fact that in terms of their phonological complexity they are equivalent. This is because a noun+possessive (*bee's*) is a complex concept and therefore relies more heavily on phonology in the discovery of its meaning than a simple noun (*nose*) whose meaning is easier to discover without much aid from phonology. A wealth of data (reviews in Bishop, 1997; Leonard, 1998) supports the prediction that the possessive *'s* is more problematic than simple nouns or even the plural *-s* in SLI.

The primacy of phonological salience in explaining the morphosyntactic profile of SLI is inherent in the surface hypothesis, which proposes that the typology of the English language in combination with a generalised processing deficit, can account for this profile (Leonard, 1998).

The surface hypothesis is rooted in cross-linguistic research on normal language acquisition which shows that the profile of language development depends on the language being learned. It is suggested that factors such as perceptual salience, redundancy, relative frequency, pronounceability, and regularity are important in determining which aspects of a particular language will be acquired earlier and more robustly (Bates & MacWhinney, 1987; Peters, 1985). In English, many grammatical morphemes are low in these features and appear in the speech of normally-developing children acquiring English later than in children acquiring other languages. It seems plausible then that these morphemes are already vulnerable in English because of their surface properties, and that the problems children with SLI have with them are attributable to these same surface properties rather than to their grammatical identity.

Even within grammatical morphology some morphemes are more vulnerable than others. It is well documented that English-speaking children with SLI have particular problems with the past tense *–ed* and third person singular *–s* inflections, with the possessive *'s*, the infinitival *to*, as well as articles (Leonard, 1989). These are all morphemes with short duration relative to the words surrounding them. Contrastingly, the progressive inflection *–ing* does not seem to pose particular difficulty: this is of much longer duration than the morphemes noted above, especially when it is in phrase-final position (which occurs far more frequently than for the other morphemes).

In Italian and Hebrew, where inflections often appear in phonological phrase-final position and are consequently lengthened, they do not seem to be problematic for children with SLI. Italian articles and direct object clitics, on the other hand, tend to occur in phrase-initial or phrase-medial positions where they are less salient, and are problematic for children with SLI (Leonard & Eyer, 1996).

According to Leonard and colleagues' ongoing cross-linguistic research it appears that both between and within languages, the surface characteristics of linguistic features determine whether or not they are vulnerable and thus likely to pose difficulty for children with SLI. The vulnerability on its own, however, does not explain why these features are more difficult for children with SLI to acquire than for their normal-language peers: it is the combination of vulnerable morphemes with a generalised processing capacity limitation that causes the problem. One possible limitation is reduced speed of processing, which prevents the morpheme in question from being fully processed before the next element in the speech stream comes along; this is particularly important for morphemes of brief duration. Note that the surface hypothesis follows the proposals of Pinker (1984) in assuming that an inflected word is perceived and then compared to its bare-stem counterpart, after which a grammatical function for the word must be hypothesised, and the word must be placed in the appropriate morphological paradigm and cell. Fully processing an inflected word thus requires not only accurate perception but also completion of complex symbolic computations.

Phonological accounts of SLI such as the phonological theory and the surface hypothesis, as their names suggest, are specified in terms of surface characteristics such as phonology. This implies an orientation toward speech perception and receptive language. However, much of the evidence describing the morphemes that are problematic SLI comes from studies of children's language productions, either in spontaneous speech or in elicitation tasks (Bishop, 1994; also reviews by Bishop, 1997, and Leonard, 1998). One morpheme that is consistently reported as being problematic, and often omitted from the speech of children with SLI, is the English regular past-tense *-ed.*

Elicitation of past tense -ed

In an investigation of past tense marking, Oetting and Horohov (1997) found that six-year-old children with SLI were able to produce correct past-tense forms in response to a probe only 50% of the time, considerably less often than younger MLU-matched controls. The difference between the SLI and MLU-control groups was heightened for regular verbs which are infrequently marked for past tense in child language. Both groups were also more likely to inflect verbs whose stem ended in a liquid or a vowel than verbs ending in a consonant which required the /d/ or /t/ suffix. Thus, frequency and phonology, both surface characteristics, played a role in productive past tense inflection in both typically developing and language impaired children.

A second task in the same study contrasted the influence of phonological and grammatical factors in productive past tense inflection, by asking children to inflect denominal verbs - which are derived from nouns - and homophonous root verbs. In proficient adult usage, denominals tend to take the regular past tense inflection ('ring'→ '*ringed* the city'), even when they have a homophonous root verb which takes an irregular inflection (e.g. 'ring' → '*rang* the bell'). The decision to inflect such homophonous pairs according to this pattern cannot rely on phonological information, since they are indistinguishable on this basis. A logical alternative is that grammatical knowledge of their derivational status will provide the key. Like children with typically-developing language, children with SLI were found to inflect the homophonous pairs differentially; Oetting and Horohov (1997) interpreted this finding as evidence that the children with SLI had a past-tense system which was sensitive to grammatical structure. This interpretation rests on the assumption that denominals and their homophonous root verbs can only be differentiated in terms of grammatical structure. However, another obvious difference between them is that they usually have different lexical meanings; Ramscar (2001) has argued persuasively that semantic factors can determine how homophonous pairs are inflected. Therefore this task cannot show unambiguously whether or not grammatical structure is intact, and the claim of Oetting and Horohov (1997) that the grammatical structure of children with SLI is intact is questionable.

Receptive tasks

Studies of productive language show unequivocally that many inflectional morphemes, among them the regular past tense morpheme *-ed*, are problematic in SLI. Is this also true of children's receptive language? An increasing number of studies have addressed this question. That even very young children with SLI are sensitive to at least some grammatical morphemes was demonstrated by McNamara, Carter, McIntosh and Gerken (1998), who used a task originally developed by Gerken and McIntosh (1993) with typically-developing 2-year-olds. 3- to 5-year-old children with SLI were asked to identify a picture which matched the target word; the target word could either appear in a grammatical sentence or in a sentence with an incorrect grammatical morpheme (e.g. *Point to* ***was*** *fork for me*, instead of *Point to* ***the*** *fork for me*). If the children were completely oblivious to the target morpheme, its incorrect use should not have affected their performance; the fact that the children with SLI chose fewer correct pictures when the incorrect morpheme was used showed that they were sensitive to it.

Looking at bound rather than free morphemes, Kamhi and Koenig (1985) reported that children with SLI found errors involving grammatical morphemes (*They playing a game*) more difficult to identify than semantic lexical errors (*Mary eats tables*); in contrast, there was no such discrepancy between grammatical and lexical error identification in the control children. Using a picture identification task, Felbaum, Miller, Curtiss and Tallal (1995) were able to show that six-year old children with SLI had greater difficulty with brief duration morphemes, such as past tense *-ed* and possessive *'s*, than with longer duration morphemes such as pronouns. English-speaking children with SLI were also slower in making grammaticality judgements and accepted more ungrammatical sentences than a group of control children (Wulfeck & Bates, 1995).

In a comparison of sensitivity to different types of ungrammatical constructions, Rice, Wexler and Redmond (1999) investigated sentences such as *He eat toast*, which were missing obligatory tense markers, as well as sentences with bad agreement (*I likes toast*) and sentences missing the progressive *-ing* inflection. Over a period of two years, children with SLI consistently lagged behind language-matched controls and accepted more ungrammatical sentences which were missing tense markers, but not those which were missing *-ing* or had bad agreement. This pattern mirrored that described in the production data, and Rice and colleagues concluded from this that they were successful in tapping the underlying grammatical representations rather than task-specific processes (or purely production limitations in the production task). The pattern of errors is consistent with the Extended Optional Infinitive (EOI) account. In addition, given that a grammaticality judgement of bad agreement sentences relies on the detection of small, non-salient grammatical morphemes (such an inappropriately placed 3rd person singular *-s*), Rice et al. argue that their results cannot be accounted for by the surface hypothesis.

The particular vulnerability of past-tense marking was demonstrated in a study by van der Lely and Ullman (1995), in which school-aged children with SLI (age range: 9;3 to 12;10) were presented with 32 real verbs (16 regular and 16 irregular) and 32 novel verbs (16 that were phonologically similar to real irregular verbs – called novel irregulars - and 16 that were phonologically distant from real irregular verbs – called novel regulars). The verbs were presented in a past tense context sentence, and each verb was presented with three different inflections on three different occasions: regular inflections (*looked, gived, prassed, crived*), irregular inflections (*leck, gave, pruss, crove*), or unmarked (*look, give, prass, crove*). The children had to say whether the verb form was "good" or "bad". In general, children with SLI were similar to the controls with respect to accepting the majority of correct forms, and rejecting irregularisations of both real and novel 'regular' verbs. However, children with SLI accepted significantly more overregularised and unmarked forms than the controls.

This study also included a past-tense elicitation (production) task, which confirmed the finding that children with SLI produce a very high percentage of unmarked (real) verb forms. Note that a direct comparison between the productive and receptive performances of these children was not reported.

The question of lower sensitivity to unmarked past-tense in children with SLI was followed up by Montgomery and Leonard (1998). An interesting twist in this experiment was the contrast between morphemes of low phonetic substance (past-tense *-ed* and third-person-singular *-s*) and high phonetic substance (present-progressive *–ing*). Children were presented with two receptive tasks, one on-line (Reaction Time) and one off-line (grammaticality judgement). In the RT task, children were asked to press a button as soon as they heard the target word, which was presented in a sentence. For half of the 84 sentences, the verb preceding the target lacked an obligatory inflection (either *–ed*, *-s*, or *–ing*); detection of the missing inflection was shown in slowed reaction time to the target word. While the control children (both age-matched and younger receptive syntax-matched controls) demonstrated RT sensitivity for both the high and the low phonetic substance missing inflections, the children with SLI showed RT sensitivity only when the high phonetic substance inflection was missing. This suggests that at least on-line, while in the act of processing the incoming speech signal, children with SLI do not fully process grammatical inflections of low perceptual salience. However, it is worth noting that this result is also consistent with the EOI hypothesis; as *-ing* is not a marker of finiteness, it would not be predicted to be particularly problematic in SLI.

In the offline, grammaticality judgement task in the Montgomery and Leonard (1998) study, children had to make a yes/no judgement about whether the sentence they heard was grammatical or not. There were 32 sentences, similar to those used in the RT task, of which 16 were missing an obligatory inflection. Children with SLI accepted more of the ungrammatical sentences when the missing inflection was of low phonetic substance than when it was of high phonetic substance. In comparison to the control groups, the children with SLI performed significantly more poorly than their age-matched controls in the low but not the high phonetic substance condition, but performed very similarly to the younger receptive-syntax matched controls for both conditions. According to a strict interpretation of the surface hypothesis, children with SLI should have shown worse performance than the younger controls, since the purported problem with low-perceptual salience material is described as going beyond a general delay in morphosyntactic ability. It is also interesting to note the overall good performance of the children with SLI in this grammaticality judgement study (average percent correct for SLI group was 86.2%, age-matched controls 89.9% and younger controls 85.4%).

The conclusion drawn by Montgomery and Leonard (1998) is that school-aged children with SLI may be able to form a normal morphological paradigm which includes non-salient morphemes, but that the pressure of on-line processing is what causes these fragile morphemes to drop off in production and real-time receptive processing. This conclusion is based on the finding that children with SLI performed badly on the RT task but reasonably well on the grammaticality judgement task; this contrasts with the van der Lely and Ullman (1995) result that roughly 70% of sentences with (erroneously) unmarked verbs were accepted by the children with SLI, while most of the controls had an acceptance rate well below 50% (note that the children in both studies were in a similar age-range).

Rationale for the current study

Given the lack of conclusive evidence, it seemed worthwhile to re-examine the question of whether children with SLI have difficulty in the receptive processing of non-salient morphemes, such as the English past-tense. Furthermore, the English regular past-tense inflection is an example of a morpheme which, while grammatically a single entity, has several allomorphs which make it phonologically heterogeneous. It is possible that even within a generally non-salient morpheme there are allomorphs of less phonetic substance which are harder to process than allomorphs of higher phonetic substance. Specifically, the syllabic /«d/ allomorph of the past-tense inflection has greater duration and amplitude than the voiced /d/ inflection, which in turn is more salient than the unvoiced /t/ allomorph. Following the surface hypothesis, one would expect that in children with SLI, there would be a gradient of difficulty in processing the three allomorphs, with /t/ being the most difficult and /«d/ the least.

The current study involved a grammaticality judgement task designed to look at this possibility. The predictions were as follows: a) children with SLI would accept as correct significantly more unmarked regular verbs in a sentence context demanding past-tense inflection, than would age- and nonverbal-ability- matched controls 2) children with SLI would make the fewest errors in the /«d/ allomorph condition and the most in the /t/ allomorph condition 3) performance on this task would relate to performance on phonological tasks, given that the argument relies heavily on the phonological salience of these morphemes. In this and the following two experiments, for ease of discussion, I will use the word 'inflection' and the phrase 'inflection type' extremely broadly to include prepositions.

Method

Participants

This study was carried out in parallel with the study reported in chapter 4. The same children participated, and their profile is identical to that described in chapter 4 (see Table 5.1 for age and Raven's matrices scores).

Mean (SD) *min - max*	**SLI** ***n* = 11**	**PLI** ***n* = 4**	**SLI-Control** ***n* = 12**	**PLI-Control** ***n* = 3**
Age (years:months)	10;4 (1:10) 7;6 - 13;0	9;4 (0;11) 8;0 - 9;8	10:5 (1;9) 7:7 - 12;9	9;2 (0;10) 8;2 - 9;6
Raven's Matrices	101.82 (11.16) 86 - 125	115.50 (9.15) 103 - 125	100 (8.08) 88 - 114	121.33 (6.35) 114 - 125

Table 5.1: Group profiles, in terms of age and nonverbal ability.

Stimuli

Twenty monosyllabic verbs were chosen for each of the three English regular past-tense inflectional allomorphs (/ɪd/, /d/, and /t/). The main criterion for these verbs was that they should be likely to be familiar to the participants; a frequency check was carried out using the CHILDES database to ensure that each verb was heard or used by 4-year old children; in almost all cases the past tense form was present at least once in the frequency count (see Appendix I). A simple sentence was then created for each verb, which made inflection obligatory. Sentences were balanced both within and between allomorph conditions for number of phrases (either 3 or 4), number of syllables before the target verb (usually 1 or 2, occasionally 3), number of syllables following the target verb (ranging from 3 to 8), and number of consonant clusters in the target verb (usually 0 or 1, occasionally 2). Target verbs were always followed by a word beginning with a vowel, in order to make the verb ending as easy to hear as possible.

In addition to the three allomorph conditions, a control condition was created using another set of 20 verbs (3 verbs with the /ɪd/ inflection, 8 with the /d/ and 9 with the /t/ inflections). In these sentences, however, the verb inflection was always present but in the ungrammatical version of the sentence a function word was missing: the target function words were *in* (8 sentences), *at* (7 sentences) and *on* (5 sentences). These were chosen because they play a grammatical function and are of relatively short duration, but have not been reported to be problematic for children with SLI. This condition was designed to be an index of a child's ability to meet the demands of the grammaticality judgement task per se. The stimuli for this condition met the same criteria and were created in exactly the same way as the three verb-inflection conditions. Appendix I lists all the sentence stimuli used.

Sentences were divided into sets A and B, which were counterbalanced for well-formedness; that is, sentences which were well-formed in set A were ill-formed in set B and vice-versa. Table 5.2 gives stimulus duration information as well as the pre- and post-target number of syllables for sentence sets A and B.

	# Syllables before target	**# Syllables after target**	**Total # Syllables**	**Well-formed (seconds)**	**Ill-formed (seconds)**
A	**1.69**	**4.95**	**7.64**	**2.57**	**2.40**
-ed	1.55	5.15	7.70	2.77	2.52
-d	1.80	4.90	7.70	2.60	2.41
-t	1.65	4.75	7.40	2.37	2.41
Prep.	1.75	5.00	7.75	2.53	2.28
B	**1.69**	**4.95**	**7.64**	**2.49**	**2.40**
-ed	1.55	5.15	7.70	2.62	2.56
-d	1.80	4.90	7.70	2.48	2.48
-t	1.65	4.75	7.40	2.36	2.35
Prep.	1.75	5.00	7.75	2.49	2.19

Table 5.2: The number of syllables before and after the target word, the total number of syllables, and the duration in seconds of the well-formed and ill-formed versions of sentences targeting the past tense allomorphs -ed, -d, and -t, as well as prepositions.

Recording and editing

The sentences were recorded using a DAT tape in a sound-proof booth, by an adult female native British-English speaker. They were read out with as normal an intonation as possible without emphasising any one word in the sentence. All the sentences were recorded in two conditions: one with the appropriate past-tense inflection on the verb, and one with the verb unmarked. Two exemplars were recorded for each stimulus, and the best one was then peak-to-peak normalised in CoolEdit and double-checked for distortion. None of the stimuli were distorted.

Procedure

The sentence stimuli were presented in the context of the 'monster game'. A green cartoon monster on the computer produced each sentence, and the child was required to say whether or not the monster "said the sentence properly". Responses were scored on-line as 'correct', 'incorrect' or 'unscoreable'. A number of practice trials were presented before beginning the task, emphasising that the judgement should be made on syntactic and not semantic grounds: most children understood this requirement very quickly, following a couple of practice trials.

Between subjects, the stimuli were presented in a block design, such that half the children heard half of the 80 stimuli in their well-formed version; these stimuli were presented in their ill-formed version for the other half of the children, and vice-versa. Within subjects, trial presentation was randomised.

The grammaticality judgement task was run on a Gateway 2000 Solo laptop, in a quiet room at school (and in one case at home), with stimuli presented over Sennheiser HD45 headphones. This task took approximately 25-30 minutes to complete.

Results

Data reduction

Responses to a grammaticality judgement task can take the form of 'yes' (I think the sentence is grammatical) or 'no' (I think the sentence is ungrammatical). This can be in response to either a grammatical or an ungrammatical sentence. Therefore there are four possible stimulus/response combinations: *hit* ('yes' response to a grammatical sentence), *false alarm* ('yes' response to an ungrammatical sentence), *miss* ('no' response to a grammatical sentence), and *correct rejection* ('no' response to an ungrammatical sentence).

Many children have a bias towards saying 'yes' (see discussion in Bishop, 1997), perhaps because they do not expect that an adult will purposely try to lead them astray. It is desirable to compensate for this bias if one wants to get an accurate reflection of whether the child can actually discriminate grammatical from ungrammatical sentences at a better than chance level. Signal detection theory provides a method for doing this, effectively assuming a forced-choice situation in which the participant must decide which of two alternatives is correct (Green, 1964). Following other investigators (Wulfeck, 1993; Rice, Wexler & Redmond, 1999), I calculated a measure of sensitivity A', which adjusts for the positive bias by comparing the proportion of false alarms to the proportion of hits. The formula used was taken from Gelfand (1998):

$$A' = (0.5 * x * y) + (y * (1 - x)) + (0.5 * (1 - x) * (1 - y))$$

where x is the proportion of false alarms, and y is the proportion of hits. Perfect performance, accepting all grammatical and rejecting all ungrammatical sentences, will give an A' of 1.00. Accepting all sentences, be they grammatical or ungrammatical, will give an A' of 0.50, that is, chance.

Although the A' statistic successfully controls for positive bias, the measure is still based on proportional data. Proportional data often have unequal variances because the variance is dependent on the mean; a larger mean tends to be accompanied by a larger variance. In order to ensure equality of variances, therefore, it was necessary to perform an arcsine transformation $Y = 2\text{arcsine} \sqrt{p}$, where p is the proportion correct, or in this case A' (Howell, 1997).

Grammaticality judgement - the past tense allomorphs

Figure 5.1 provides an overview of the mean A' scores for the past tense and prepositions conditions of the grammaticality judgement task.

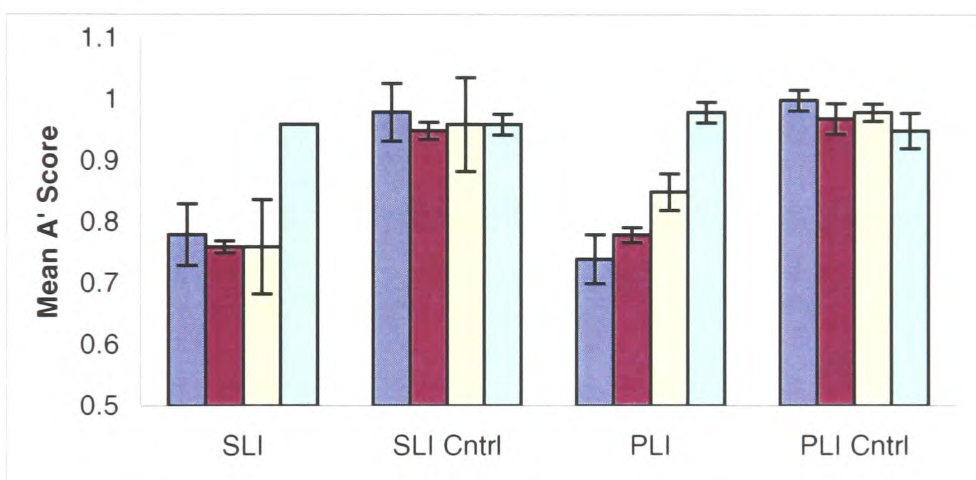


Figure 5.1: Mean A' scores for the past-tense and control conditions, for SLI, SLI Control, PLI, and PLI control groups. Scores represent proportional data, and are not arcsine transformed. [Blue = /ɪd/, Maroon = /d/, Yellow = /t/, aqua = prepositions]

It is clear from Figure 5.1 that while the control groups have virtually error free performance in all four conditions (three past-tense allomorphs and prepositions), both language impaired groups have poor performance on the past-tense conditions and have nearly ceiling performance on the prepositions conditions. Note that although the past tense is clearly problematic for the language impaired groups, performance is still well above chance levels. The difficulty with the past tense is expected, and is consistent with the literature on grammatical morphology in SLI. However, there does not seem to be any differentiation between the past tense allomorphs for any of the groups (except for a slight trend in the PLI group), which is contrary to the experimental prediction.

A 2 (group) x 4 (inflection condition) repeated-measures analysis of variance was carried out to examine the effect of inflection condition (within-subjects factor) in the SLI and SLI Control groups (between-subjects factor). There was a significant main effect of inflection condition [$F\ (2.15,45.13) = 8.00$, $p < .01$], a significant main effect of group [$F\ (1,28) = 18.05$, $p < .001$], and a significant interaction between inflection condition and group [$F\ (2.15,45.13) = 6.06$, $p < .01$]. The data (Figure 5.1) suggests that the effect of inflection condition, as well as the interaction with group, is due to the good performance of the SLI group in the prepositions condition. When the analysis of variance was repeated without this condition, giving a 2 (group) x 3 (inflection condition) design, the main effect of inflection (i.e. past tense allomorph) condition disappeared [$F\ (2,42) = 1.14$, $p > .05$], as did the interaction with group [$F\ (2,42) = 0.40$, $p > .05$]. The main effect of group, on the other hand, remained significant [$F\ (1,21) = 20.41$, $p < .001$]. The pattern of results suggested by Figure 5.1 is thereby statistically confirmed, and the effect of allomorph shown to be non-significant. There is no evidence that there is the predicted gradient of sensitivity according to an allomorph's salience, such that /ɪd/ is more robust, /t/ least robust, and /d/ intermediate. However, there is strong evidence for poor performance on past tense in SLI relative to controls.

Grammaticality judgement and phonological tasks

The second experimental prediction was that performance on the grammaticality judgement task, and in particular the past-tense conditions, would correlate with performance on the phonological tasks (using the data reported in chapters 3 and 4). As there was no difference in performance between the three past tense allomorphs, these were collapsed into a single measure of 'past tense', which was correlated with the phonological discrimination, nonword reading, and nonword repetition scores. The correlations between 'past tense' and performance on the three phonology tests are reported in Table 5.2. This shows that when all participants were included, past tense grammaticality judgement was found to correlate significantly with phonological discrimination and nonword reading, but not nonword repetition. These correlations remained significant even when the factors of age and general language level (as reflected in the BPVS score) were partialled out.

	Bivariate correlation *n = 30*	**Age partialled out** *df = 27*	**BPVS partialled out** *df = 27*	**Age & BPVS partialled out** *df = 26*
Phonological Discrimination	**.67***	**.66***	**.50***	**.51***
Nonword Reading	**.70***	**.67***	**.53***	**.55***
Nonword Repetition	.21	.24	.24	.26

Table 5.2: Bivariate and partial correlations between past tense grammaticality judgement and phonological discrimination, nonword reading, and nonword repetition. Bold indicates significance at the .05 level; an asterisk indicates significance at the .01 level.

The strength of the correlation between past tense grammaticality judgement and the tests of phonological discrimination and nonword reading is consistent with the experimental prediction; it is particularly interesting that this relationship stands independently of the contribution of the general language level, at least as reflected in receptive vocabulary. It is the pattern that one would expect to see if phonological processing, and particularly at the perception and discrimination level of receptive phonology, were important for perceiving and processing grammatical inflections.

However, given that the children with language impairment were poorer than control children at both the past tense conditions of the grammaticality judgement task and the phonological tasks, it may be that the correlations reported above simply reflected between group differences in performance. The argument in favour of phonological sensitivity being implicated in inflectional sensitivity would be much strengthened if these correlations could be shown to exist within the language impaired and control groups.

This was not unequivocally the case. Within the language impaired group (SLI and PLI were combined as their patterns of performance are very similar), the correlations between past tense grammaticality judgement and the two phonological tasks remained moderately strong, though non-significant: phonological discrimination [r_s (7) = .46, $p > .05$], nonword reading [r_s (7) = .42, $p > .05$]. By contrast, these correlations were negligible within the control group: phonological discrimination [r_s (8) = .10, $p > .05$], nonword reading [r_s (8) = -.24, $p >$,05]. However, caution is indicated in interpreting these correlations for the control group alone, as there may well be a confound from the near-ceiling performance of this group on the grammaticality judgement task.

Age effects

When the correlation between performance on the grammaticality judgement task and chronological age was computed including both language impaired and control groups, the effect of age was negligible. Examining both groups separately, however, gave rather different patterns of results (Table 5.3). While there was a significant improvement with age within the control group (although the trend was noticeably weaker for the past tense composite alone), there was no similar improvement within the language impaired group (SLI and PLI groups were collapsed, as both had similar outcomes).

	All participants *(n = 30)*	**LI** *(n = 15)*	**Controls** *(n = 15)*
Past tense	.08	-.16	.26
Total	.19	-.19	**.68***

Table 5.3: Bivariate correlations between chronological age and A' scores on the grammaticality judgement task, for a composite of past tense conditions, and a total composite score. Bold indicates significance at the .05 level; an asterisk indicates significance at the .01 level.

Grammaticality judgement and FM

As the same children participated in both this study and the study reported in chapter 4, it was possible to compare directly performance on the grammaticality judgement task, and FM sensitivity. There was a very slight trend for good past tense sensitivity to correlate with low 2 Hz FM thresholds [r_s (30) = -.25, $p > .05$], but not to 20 Hz FM [r_s (30) = .18, $p > .05$] or 240 Hz FM thresholds [r_s (30) = -.00, $p > .05$]. Since this relationship would be expected to be mediated by speech perception, and the link between slow FM sensitivity and phonological discrimination (as the closest measure available for speech perception) was found to be far from clear in this group of children, it is not surprising to find a low correlation between grammaticality judgement and FM.

Discussion

The experimental hypothesis suggested that phonological ability underlies, or at least is related to, the perception of the grammatical morphemes which pose particular difficulty in SLI. This hypothesis would be supported by a gradient of difficulty within the English regular past-tense inflection, such that the fewest errors were made with the most perceptually salient allomorph /◀◀d/, and the most errors with the least salient allomorph /t/. It would also be supported by a strong correlation between performance on the phonological measures and performance on the grammaticality judgement task.

Assessment of task demands

The aim of the grammaticality judgement task used in this study was to obtain a measure of children's sensitivity to past tense inflections and prepositions. However, measures obtained from behavioural tasks are rarely, if ever, pure reflections of an individual's skill in the targeted domain, and are usually confounded with the ability to cope with more general task demands. For example, there is always the possibility with any task which requires reflection on language itself rather than on the message it carries, that what is being assessed is metalinguistic rather than linguistic ability (Kamhi & Koenig, 1985). Having to treat language outside a normal communicative context, and failing to appreciate that language consists of discrete elements (phonemes, syllables, words) could result in poor performance on a task like grammaticality judgement, even in the face of intact linguistic competence. Therefore, the fact that in this study, children with SLI approached ceiling performance on the control condition was very important in establishing that the task was appropriate, and did not make metalinguistic demands which the children were unable to cope with. On this basis, responses could confidently be treated as genuine judgements of the grammaticality of the sentence stimuli.

An observation made during testing and may be relevant here: some of the children with SLI, when doing the grammaticality judgement task, repeated the sentence to themselves and then answered 'wrong' or 'right' according to how they produced the sentence, rather than how the monster had produced it. Clearly the task was not directly accessing the children's initial perception of the stimulus, and some kind of metalinguistic processing was taking place. Possibly the children were absorbing the stimulus into their faulty past-tense paradigm, and then producing the output of this paradigm as they would in spontaneous speech, without being aware that there was anything wrong with this construction. However, the fact that the SLI group performed well above chance argues against a fatally flawed morphological paradigm. Note that this 'repetition before decision' strategy was not observed for stimuli in the control condition. A reasonable conclusion to draw from these observations is that there was an interaction between the metalinguistic demands of the task and the particular linguistic construction being tested, such that difficulties with processing a vulnerable inflection like the past tense were exacerbated by the task demands, while more robust morphemes like the prepositions remained unaffected. However, the pattern or level of errors made by the children who repeated the stimuli to themselves was no different to that of the children with language impairment who did not, although it is possible that these children were silently repeating the stimulus.

With the proviso that the grammaticality judgement task was not a pure measure of the state of children's linguistic representations, given the near-perfect performance on the control condition, as well as the above-chance performance on the past-tense conditions, it seems safe to say that it gave a reasonable estimate.

Sensitivity to the past tense -ed inflection in SLI

The results of the grammaticality judgement task in the current study confirmed that children with SLI have receptive problems with the English regular past-tense inflection in addition to the well-documented problems in production. The language-impaired children (SLI and PLI combined) had over 8 times as many errors as the normal-language children, in the past-tense conditions but not the control (preposition) condition.

The predicted gradient of difficulty was not seen in either language impaired or control groups. It seems likely that a ceiling effect obscured any patterns in the control group, since the average error rate on the past-tense conditions was under 5%. However, even in the SLI group, where performance on the past tense conditions was not at ceiling, there was no significant effect of past-tense allomorph, nor was there even a trend for the predicted - or any other - pattern of errors.

Zero-marking alveolar-final verbs

An alternative to the prediction that the syllabic /«d/ would elicit the fewest errors was the reverse, that is, that children would have a greater tendency to accept sentences missing this allomorph. This would have paralleled an effect often found in young children with normally developing language: verbs with stems that end in an alveolar consonant (such as /t/ or /d/) are far more likely to be zero-marked (i.e. remain unchanged from the stem) than verbs ending in other phonemes, and it is these verbs that require the syllabic /«d/ inflection (Bybee & Slobin, 1982). Oetting and Horohov (1997) looked at productivity of past-tense inflection in children with SLI, and found that verbs that required the /«d/ suffix were produced correctly significantly less often in the SLI group than in the age-matched control group (though not the MLU-control group). However, only four verbs requiring the /◀◀d/ suffix were included in their stimuli, so it would be difficult to predict whether this effect was specific to the items they used or to /◀◀d/ verbs in general. Marchman, Wulfeck and Ellis Weismer (1999) also looked at productivity of past tense inflection in SLI, and found that alveolar-final verbs were highly susceptible to zero-marking, and especially in the case where the past tense forms had low frequency in the child's language environment. They included 5 regular and 12 irregular alveolar-final verbs in their stimuli, and found that the effects of stem-final phonology and frequency occurred for both regular and irregular verbs (although note that zero-marking an irregular verb is not always an error). A pertinent point for this discussion is that amongst irregular verbs, the largest class is that of no-change verbs, such as hit → *hit* (Marcus et al., 1992); further, all no-change irregular verbs end in either /t/ or /d/. Since many irregular verbs have high frequencies, a reasonable assumption for young language-learners would be either that a verb ending in /t/ or /d/ does not need to be changed for tense marking purposes, or that it is already appropriately marked for past tense. Either of these assumptions would allow the child to accept as grammatical a sentence like *Yesterday I lift the box.*

The idea that high incidence of zero-marking for alveolar-final verb stems may reflect its use as a viable alternative to suffixation, is consistent with the arguments of the Extended Optional Infinitive account (Rice & Wexler, 1996): that is, that children with SLI are essentially extending a period seen in the course of early normal language development, in which inflections are seen as optional rather than obligatory. However, the Marchman et al. (1999) finding that the phonological composition and frequency of the verb strongly affect how that verb will be inflected, suggests that it is these surface features and not the grammatical identity of the verbs that drives the pattern of erroneous inflection seen in both younger normal-language children and children with SLI.

The results of the current study do not show any evidence of differential treatment for the syllabic /◄◄d/ ending, in either direction. The mean A' score for language impaired children was M = .77 (SD = .16) in the /◄◄d/ condition, M = .76 (SD = .15) for /d/, and M = .79 (SD = .12) for /t/. The phonological composition of the stem ending, and the associated past tense allomorphs, had no effect on the children's grammaticality judgement. One might speculate that the perceptual salience of the syllabic /◄◄d/ and the tendency to zero-mark alveolar-final verbs cancelled each other out, but these factors are confounded in the current experiment and cannot be teased apart. The lack of an effect of allomorph is inconsistent with the experimental prediction that perceptual salience will influence children's sensitivity to a missing obligatory past tense inflection.

Correlation with phonological tasks

A very high correlation was observed between performance on the past-tense conditions on the grammaticality judgement task and phonological ability as indexed by phonological discrimination and non-word reading, though not non-word repetition. Although a strong relationship was also seen between perception of past-tense inflection and general language measures such as vocabulary and sentence repetition, these could not account for the correlation with phonological discrimination and decoding. Age was another possible factor that could potentially explain away the relationship, since the grammaticality judgement scores are not adjusted for age (and nor are the phonological discrimination scores). However, partialling out age had very little effect.

Of the three phonological tasks, phonological discrimination is the most low-level and the most directly dependent on the perceptual salience of word endings. The strength of this task's correlation with past tense scores suggests that a similar process may be utilised in making grammaticality judgements, and that the low salience of the past tense inflection (even the syllabic /⏪d/) is responsible for language impaired children's apparent insensitivity to it.

However, there is reason to be cautious about interpreting the phonological discrimination results in this way. All the phonological discriminations in the specific task used, targeted the phonemes /t/ and /s/, and the clusters /ts/ and /st/, because these are important sounds in English inflectional morphology. Consequently, the task could be described as 'morphological discrimination', and insensitivity to these distinctions could be attributed to grammatical deficits as easily as to phonological deficits (Marslen-Wilson, personal communication).

Tyler, Randall & Marslen-Wilson (2002) propose the existence of a specialised morpho-phonological processing system, which functions separately from other phonological processes. They base this idea on the finding that adult patients with Broca's aphasia made significantly slower discrimination judgements for real regular verb pairs (*call/called*) than they did for uninflected words that were phonologically matched (*ball/bald*). Additionally, there was no consistent relationship between patients' performance on this task and scores on a set of phonological processing tasks, some of which required minimal pair discriminations. The authors argue that there must be something beyond the phonological composition of the regular verb pairs that makes them so problematic for the patients, and that this something must be their morphology. This conclusion assumes that the only factors which are important in the inflectional process are phonology and morphology, and does not take into consideration the influence of semantics (Ramscar, 2001). However, semantics cannot account for the phonological discrimination results in the children I studied, because a large proportion of the stimuli were nonwords. The relationship between phonological discrimination and grammaticality judgement must be attributable to either purely phonological, or Tyler et al.'s putative morpho-phonological processes. One factor that suggests the former is that the nonword reading task also correlated with the grammaticality judgement task (and with the phonological discrimination task); the stimuli in the nonword reading task ended in a broad range of phonemes, most of which could not be considered to be inflections.

From phonology to grammatical inflections

Similar links between phonological processing and tense-marking have recently been discussed by Norbury, Bishop and Briscoe (2001). In findings which echo those reported by Oetting and Horohov (1997), as well as Marchman et al. (1999), Norbury and colleagues found that the phonological complexity and frequency of verbs exerted significant influence on the way they were inflected for past tense by children with language impairment (note that some of these children also participated in my study). Furthermore, children with SLI who had difficulty with finite verb morphology also did poorly on nonword repetition and recalling sentences tasks, both of which tax phonological memory.

These data, as well as the correlation reported in the current study between phonological discrimination, nonword reading and grammaticality judgement for the past tense *-ed* inflection, are not congruent with the predictions of linguistic accounts of the grammatical deficits in SLI. While linguistic accounts such as the Extended Optional Infinitive (Rice, 2000) and the RDDR (van der Lely, 1997) do not deny that children with SLI may have phonological impairments in addition to their syntactic impairment, they maintain that the two are separate. They would not predict a relationship between them which stands independently of general language level, of the type reported in the present study. Such a correlation is, on the other hand, entirely consistent with phonological accounts of SLI, such as the surface hypothesis (Leonard, 1998) and the phonological theory (Chiat, 2001).

By contrast, the finding that there was no effect of the different salience of the three past tense allomorphs (/«d/, /d/, and /t/), is not consistent with the predictions of phonological accounts of SLI.

In an interesting twist to this story, recent findings by Adams and Bishop (2002) suggest that while phonological and grammatical deficits co-occur in many children with SLI, they may have separate heritability. Although this does not mean that a phonological and grammatical deficit will not interact during language development, it does leave open the possibility that a grammatical deficit may, after all, occur independently of a phonological deficit.

Chapter 6: Simulating SLI

Introduction

One of the key questions in the study of SLI is whether there is a primary representational deficit in the 'grammar module' or whether more general-purpose processing mechanisms can account for the linguistic deficits, without invoking an independent module for grammar.

If it were possible to demonstrate that the specific profile of language difficulties seen in language impaired individuals does not depend upon impaired linguistic representations, this would provide strong support for a processing explanation of SLI. Such a demonstration has been reported in the adult aphasia literature.

Broca's aphasia (also often referred to as agrammatism) is frequently described in terms of a selective grammatical deficit. Although content words and associated world knowledge seem to be spared, patients frequently omit function words and inflectional morphemes, or substitute them with uninflected forms of words. Further, they have impaired comprehension of sentences in which syntax is the only guide to disambiguating meaning: *The girl was chased by the bear* can be understood using the semantic information available, as the bear is far more likely than the girl to be doing the chasing. However, *The wolf was chased by the bear* can only be comprehended using syntactic knowledge, since the wolf and the bear are equally likely to chase each other.

Traditional accounts of agrammatism have explained these deficits in terms of a 'central syntactic deficit', or loss of grammatical knowledge (Caramazza & Zurif, 1976; Caplan, 1981). More recently, evidence that patients with Broca's aphasia can make grammaticality judgements with above-chance accuracy on the very sentences which they cannot comprehend suggests that there cannot be loss of all grammatical knowledge (Shankweiler et al, 1989; Wulfeck & Bates, 1991). A revised representational account therefore posits a more limited 'closed-class hypothesis' (Zurif & Grodzinsky, 1983; Friederici & Graetz, 1984), in which word order is spared and inflection and function words are selectively impaired (this is in line with the observation that agrammatic patients rarely, if ever, say 'tree the' instead of 'the tree').

An alternative to a representational account is a processing account of language, both typical and atypical. The Competition Model (MacWhinney & Bates, 1989) suggests that human cognition is driven by mechanisms which interact with the structure of information in the environment. In the case of language, they posit the concepts of 'cue validity' and 'cue cost'; whether a particular linguistic structure in a given language is informationally rich, reliable, and available, and whether it incurs high processing costs (for example, it may be infrequent or perceptually non-salient). English is an inflectionally impoverished language: inflectional morphemes are few and far between, often in unstressed phrase-final positions, and of brief duration; most information in an utterance can be extracted without them. Word-order, on the other hand, is a very valid, low-cost cue in English: sentences are predominantly in Subject Verb Object order, so that information about who-did-what-to-whom can easily and reliably be extracted from word-order.

In stark contrast to English, inflectionally rich languages such as Italian, German, or Greek, have far less reliable word-order, and convey far more information in inflectional morphemes; these are typically more frequent, stressed, and salient than their grammatical equivalents in English. According to the Competition Model, cues which have high validity and low cost, whatever their grammatical function, are likely to be robustly represented, and relatively resistant to damage in the face of a global reduction in processing capacity. It is the specific structure of a given language, rather than a specifically linguistic mental process, that determines the apparently linguistically specific deficits seen in acquired language disorders.

A number of studies have now shown that an agrammatic profile can be induced in the normal population, with the aid of a general processing stressor. One possible type of stressor is peripheral: a degradation of the signal. Kilborn (1991) compared performance of German and English-speaking subjects on a sentence-interpretation task, in which subjects had to decide which of two nouns is the actor in the sentence. Under normal conditions, English speakers relied heavily on word order, while German speakers relied more on morphological information. However, when a low-level noise mask was introduced into the sentence stimuli, the two language groups were differentially affected: English speakers were unaffected by the stimulus-degradation, while German speakers made much less use of grammatical morphology and compensated by increasing reliance on word order information. Thus, "a global reduction in processing capacity can affect some aspects of language more than others".

A second possible type of processing stressor is central: instead of degrading the input, the load on cognitive resources is increased. Subjects in the Blackwell & Bates (1995) study, had to remember a string of digits at the same time as doing a grammaticality judgement task. The task involved three different error types: agreement errors (*He are cooking dinner*), omission errors (*He cooking dinner*), or transposition (*He cooking dinner is*). Increasing the number of digits to remember produced the same profile of difficulty as that seen in Broca's aphasia: agreement errors were the most vulnerable (hardest to detect under stressed conditions), while omission and particularly transposition errors were robust (easy to detect even under stressed conditions).

The idea of memory as an important factor in aphasic-like language processing was thoroughly explored by Miyake, Carpenter and Just (1994). They based their approach on the Carpenter and Just (1989) model of verbal working memory, in which verbal processing and storage share one 'computational arena'; the consequence of having this shared resource is a trade-off effect such that when storage capacity demands are high, processing suffers. Subjects in the Miyake et al. (1994) study were divided into groups of high, medium, and low working memory capacity (assessed using the Reading Span Test, Daneman & Carpenter, 1980). Each subject was then presented with two versions of a sentence comprehension task: a fast (120 ms/word) and a slow (200 ms/word), using a Rapid Serial Visual Presentation paradigm (written words presented successively, each for a brief interval, in the same position on a computer monitor). There were 11 sentence types, differing in syntactic complexity, most of which had been previously tested with aphasic patients (Caplan, Baker & Dehaut, 1985). It was anticipated that normals in the speeded condition would show the same pattern of difficulty across sentence types as individuals with aphasia. This prediction was confirmed; moreover, speeded presentation rate had the greatest impact on those subjects with smaller working-memory capacity. Once again, a selective linguistic deficit was elicited by reducing a general processing capacity (in this case, verbal working memory).

However, it should be noted that the RSVP paradigm used in the Miyake et al. (1994) study could be described as a relatively unnatural language situation, and so it may be inappropriate to draw close comparisons between performance on this task and typical language use. On the other hand, the issue of ecological validity is a thorny one: one could argue that matching sentences to pictures, or judging the grammaticality of sentences are also relatively unnatural uses of language.

Finally, a recent study by Dick et al. (2001) directly compared the effects of a number of peripheral as well as central stressors, on a sentence comprehension task. Four sentence types were examined: Active *(The cat is scratching the dog)*, Subject-Cleft (*It's the cat that is scratching the dog*), Passive (*The dog is scratched by the cat*), and Object-Cleft (*It's the dog that the cat is scratching*). It was anticipated that, as with the group of aphasics tested under normal conditions in the same study, the active and subject-cleft sentences would prove to be the most robust, while passive and object-cleft would be more vulnerable under conditions of cognitive stress. The reasoning is that the word-order in both passive and object-cleft sentences (Object Verb Subject, and Object Subject Verb) has very low frequency in English, compared to the more canonical active and subject-cleft sentence types (Subject Verb Object), which are predominant in the language. According to a distributive account of language processing, low frequency structures will be less robustly represented, and thus particularly vulnerable to a general processing stress.

The peripheral stressors used in this study were a noise mask (at 50% of maximum signal-to-noise ratio) and a low-pass filter (at 600 Hz). The central stressors were speech rate compression (to 50% of the original signal), and a visual and auditory version of a 6-digit load (subjects had to judge whether the same string of 6 digits was presented before and after the comprehension task). Each of these was tested independently, as well as in dual-stressor combinations. Apart from the two digit-load conditions, all stressors independently induced a profile of difficulty similar to that seen with aphasic patients, in which passives and object-clefts were much more difficult than actives and subject-clefts. In combination, adding the digit-load in either the visual or auditory modality to another stressor had very little effect. By contrast, combining the speech compression with the low-pass filter manipulation had dramatic effects, producing not only a qualitative but also a quantitative simulation of aphasic performance on the comprehension task.

The lack of an effect of digit-load is surprising, particularly since it appears to be in conflict with the findings of Blackwell and Bates (1995). The authors suggested that the digit-task they used is simply easier than the perceptual stressors, requiring only recognition rather than more effortful recall of digits; thus it may have had less effect on the 'strong cue' (in English) of word-order. Blackwell and Bates (1995) were looking at the 'weaker' (in English) language structures of agreement morphology, which may have been more vulnerable to a less-stressful stressor. On the other hand, since grammaticality judgement tasks (as used by Blackwell and Bates) are themselves meant to be less demanding than sentence comprehension tasks (as used in the Dick et al., 2001), one might expect that even a 'weak' stressor should have an observable effect on task performance. The role of memory in this type of situation is worthy of further examination, particularly in light of the strong claims made by Miyake et al. (1994).

Given the wealth of evidence suggesting that a general processing mechanism may be able to account for an acquired, adult grammar-specific deficit, it seems reasonable that a similar explanation might be appropriate for what is often described as a developmental grammar-specific deficit: SLI.

What types of 'general processing mechanisms' might be involved in SLI? Two candidates which, appear fairly consistently in the literature are 'speed of processing' and 'verbal short-term memory'.

Speed of information processing

There is a substantial amount of research showing that children with SLI tend to be slower (generally gauged using a reaction time – RT - measure) than their peers on a wide range of tasks, both verbal and nonverbal. Nonverbal examples include mental rotation of unfamiliar shapes (Johnston & Ellis Weismer, 1983), scanning short-term memory (Sininger, Klatsky & Kirchner, 1989), peg moving and bead threading (Bishop, 1990; Powell & Bishop, 1992), and even the very simple RT measure of pressing a panel after hearing a tone or seeing a light (Hughes & Sussman, 1983; Nichols, Townsend & Wulfeck, 1995). Verbal examples include word monitoring (Stark & Montgomery, 1995), picture naming (Lahey & Edwards, 1996; Leonard et al, 1983), and grammaticality judgments (Wulfeck & Bates, 1995).

These findings led to the proposal of a Generalised Slowing Hypothesis (Kail, 1994), which suggests that children with SLI are slower than their language-normal peers at processing each component of any given task by a constant proportion. For example, picture naming may be broken down into a number of different steps: recognising the picture, retrieving its name, producing the phonological output. Each step will be slower than normal by a constant proportion, resulting in an RT for children with SLI which is a function of the RT of typically-developing children: $RT_{SLI} = m \times RT_{Normal}$. Kail (1994) used a meta-analysis of five studies to test this hypothesis, and showed that a proportional function could account for 96% of the variance in RT data from children with SLI, for a range of different linguistic and non-linguistic tasks. He estimated that the general slowing was approximately 30%. Windsor and Hwang (1999) found further support for this model with a meta-analysis of three studies; they too were able to account for 96% of the variance with the proportional function, although their estimate of the proportion of slowing was slightly lower than Kail's at 20%.

More recently Miller, Kail, Leonard and Tomblin (2001) directly compared RT data across a range of linguistic and non-linguistic tasks, for the same group of children. An interesting twist to this study was that as well as groups of children with SLI and IQ-matched controls, they also included a group of children with non-specific language impairment (whose IQ was lower than the other two groups, although within the normal range). Both language-impaired groups were slower than the control group across the board, with the NLI group showing significantly greater slowing (at 30%) than the SLI group (20%). This is in line with the argument that the greater the general deficit in processing speed, the more widespread the subsequent cognitive difficulties (the correlate of this being that a milder general deficit will result in a more selective profile of difficulty). However, for both groups, the degree of slowing was identical for both linguistic and non-linguistic tasks. This appears to contradict the hypothesis that language is disproportionately vulnerable to a general processing deficit, compared to non-linguistic cognition. It is possible, though, that this is an artefact of the experimental situation; in real-world situations (as opposed to controlled experiments), the rate of incoming language that must be processed inevitably demands much greater speed of processing than other cognitive functions. Finally, Miller et al. confirm earlier reports that generalised slowing appears more consistently in individual children who have both production and comprehension difficulties, rather than children with a problem limited to production.

Verbal short-term memory

Apart from speed of processing, the other main candidate for a deficient processing mechanism in SLI is verbal short-term memory (note that these are not mutually exclusive deficits!) According to Baddeley's (1986) articulatory loop model of verbal short-term memory, incoming phonological information is held temporarily in a capacity-limited phonological store; the memory trace in the store is maintained and strengthened by a subvocal rehearsal process, while other cognitive tasks (such as comprehension) are performed. If either storage capacity or rehearsal are damaged, comprehension will be adversely affected.

Gathercole & Baddeley (1990) showed that children with SLI had greater difficulty repeating 3- and 4-syllable nonwords compared to 1- and 2-syllable nonwords, while mental-age and vocabulary-matched controls did not show this length effect. This was interpreted as demonstrating that children with SLI have impaired phonological memory. It was further suggested that this may account for their below-age vocabulary ability, since word learning requires access to stable and distinct phonological representations.

A number of subsequent studies have also found evidence of impaired phonological memory in SLI. Montgomery (1995) demonstrated that children with SLI repeated fewer multisyllabic nonsense words than language-matched controls, but showed the same phonological similarity effect; that is, lists of phonologically similar words were harder to recall than dissimilar words, presumably because there was less interference between phonological representations. This suggests that the difficulty is not in encoding the phonological representation, but in storing and maintaining it. The question of encoding versus maintenance of representations remains unclear, however, as the children with SLI in this study were also shown to have reduced phonological discrimination ability, particularly with multisyllabic nonwords (contrary to Gathercole & Baddeley, 1990). A similar finding was reported by James, van Steenbrugge and Chiveralls (1994), who found reduced phonological discrimination using monosyllabic words and nonwords; these researchers also found limited nonword repetition in their SLI group. It is possible therefore that the apparent memory deficit in tasks like nonword repetition may be partially attributable to a poorly specified phonological representation stemming from a perceptual discrimination deficit.

Nevertheless, the evidence for some kind of verbal short-term memory impairment in SLI remains strong, and may be able to explain not only lexical but also syntactic and even morphological difficulties. Many sentence types which prove problematic in SLI, including passive constructions, centre-embedded clauses, and semantically reversible sentences, have a high memory load (Gathercole & Baddeley, 1993). *The dog was bitten by the cat*, for example, cannot be fully analysed without maintaining in memory information about the object until the end of the utterance, when it can be matched up with the subject.

Montgomery (1995b) reported that children with SLI performed poorly relative to language-matched controls on a sentence comprehension task, when the sentences contained redundant information. Thus, while children with normally-developing language found *The dirty little boy climbs the great big tall tree* no more difficult than *The little boy climbs the tree*, children with SLI found the longer sentence significantly more difficult. Importantly, there was a strong correlation between performance on the redundant sentence condition and performance on a nonword repetition task, indicating that sentence comprehension difficulties are very likely to be due to reduced phonological memory capacity.

A complication in this picture emerges when off-line and real-time sentence processing tasks are compared. In Montgomery (2000), verbal short-term memory did not correlate with a real-time word-monitoring task, although the earlier finding of a correlation between working memory capacity and off-line sentence comprehension was replicated (despite the use of a different measure of working memory).

Rather than the nonword repetition task associated with Baddeley's phonological loop model, children in this study were given a real-word free recall task based on the Daneman and Carpenter (1980, 1983) model of verbal working memory, discussed earlier; children with SLI performed poorly relative to age-matched controls (though not relative to the younger language-matched controls).

The off-line sentence comprehension task was similar to the Montgomery (1995) task, in which sentences were made longer by one of four (increasingly difficult) means: double marking of number, extra verbiage, single embedded clause, and double-embedded clause. As anticipated, children with SLI performed relatively poorly on the redundant sentence condition, and the author attributes this to the increased demands in working memory for longer sentences. It should be noted here that this interpretation depends on the redundant sentences differing from their nonredundant equivalents solely on length rather than syntactic complexity: although Montgomery argues that they do, it is debatable whether a sentence containing a double-embedded clause can be said to be syntactically simple. Nonetheless, the correlation with working memory, as well as previous studies showing the same pattern or results, suggest that memory load is at least partially responsible for redundant sentences being problematic for children with SLI.

In stark contrast (and rather unexpectedly from a processing-account viewpoint!) there seemed to be no clear relationship between verbal short-term memory and the real-time word-monitoring task. For this task, target words were embedded in either the 5th, 7th, or 10th word position in a test sentence, and reaction times were gathered for children's button-press on hearing the target word. In typical sentence processing, there is an RT advantage for later word positions, as contextual information builds up over the course of the sentence. It was expected that if children with SLI had difficulty maintaining verbal information in memory during sentence processing, they should not show this position effect. However, they did show this effect, although their performance was overall slower than the control groups', suggesting that there is simply slower linguistic retrieval rather than a memory deficit. Additionally, there was no correlation between performance on this task and the working memory task. Given that processing accounts tend to refer to the pressure of processing language on-line, this finding may be problematic. It will be important to clarify what the differences are between real-time and off-line sentence processing in language-impaired children, especially with regard to their demands on working memory. The position of Tyler (1992) on typical adult real-time language processing may be helpful here: namely, that independently of working memory demands, on-line tasks can access listeners' unconscious mental representations.

Nonetheless, it appears clear that verbal working-memory is likely to be impaired in many children with SLI, and that this may contribute to poor off-line sentence processing.

Rationale for the current study

Taking into account the evidence for general processing deficits in SLI, in the form of memory and speed of processing constraints, this study set out to explore whether SLI could be simulated in young children with typically developing language, when demands on memory and speed of processing were increased. The obvious question was which area of language processing to focus on, and how to define an SLI profile of performance.

Children with SLI are notoriously bad at inflectional morphology; it seems to be an area of disproportionate difficulty even relative to their generally poor grammatical and lexical skills. A plethora of studies has shown that compared to MLU-controls, children with SLI produce far fewer inflectional morphemes in both spontaneous and elicited speech samples. There is also a handful of studies showing that this weakness is present in receptive as well as expressive language (Felbaum et al., 1995; Kamhi & Koenig, 1985; van der Lely & Ullman, 1995; Wulfeck and Bates, 1995; chapter 5 of this thesis).

Furthermore, there seem to be areas of disproportionate difficulty even within inflectional morphology. A number of studies suggest that verb-phrase morphology is more problematic than noun-phrase morphology. For example, in a discriminant function analysis, Gavin, Klee and Membrino (1993) found that frequency of verb-phrase errors was the variable that discriminated best between children with SLI and typically-developing peers in a pre-school sample. King, Schelletter, Sinka, Fletcher and Ingham (1995) found that at school age, children with SLI used 3rd person singular *-s* and past tense *-ed* less frequently than their peers. Rice, Wexler and Cleave (1995) also found that these inflections were used far less frequently by five and six-year old children with SLI, than by MLU-matched controls. In the case of the 3rd person singular *-s*, the SLI group used the inflection appropriately in only 30% of obligatory contexts, compared to 45% for the MLU-matched group and 90% for the age-matched group. For regular past tense *-ed*, use was even lower in the SLI group, at 23%, compared to 53% in the MLU controls, and 90% in the age-matched controls.

Not all verb-phrase inflections show these dramatic differences, however. For example, progressive *-ing* appears to be acquired at the same MLU stage for both language-impaired and language-typical children (Leonard, 1998).

In the noun-phrase, the most intensely examined inflection has been the plural *-s*, which is among the earliest morphemes to be acquired in normal language development (de Villiers & de Villiers, 1973). In a comparison with same-age peers, children with SLI were found to produce this inflection far less frequently: 68% versus 93% of obligatory contexts (Roberts, Rescorla & Borneman, 1994). In comparison with MLU-controls, children with SLI still produced plural -s less frequently (83% versus 93%), but the disparity was much smaller than that for 3rd person singular *-s* (Rice & Oetting, 1993). An interesting observation in this study was that the plural *-s* was more likely to be omitted if the noun was preceded by a quantifier (e.g. three bear). A further study by Oetting & Rice (1993) found no differences in use of the plural *-s* between children with SLI and MLU controls.

It seems fair to say that overall, greater difficulty does seem to appear in verb-phrase inflections, with regular past tense *-ed* being perhaps slightly more problematic than third person singular *-s*, and that the noun-phrase plural *-s* inflection, while hardly robust, is less problematic than either of the verb inflections. It is worth bearing in mind that the 3rd person singular *-s* is very much rarer in spontaneous speech than the past tense *-ed* (Bishop, 1994), which makes it difficult to compare the two verb inflections directly.

The current study attempted to replicate this profile of difficulty in a group of six-year old children with normally developing language, by increasing memory and speed-of-processing loads within a grammaticality judgement paradigm. The predictions were that the speed-of-processing load (sentences presented at 50% speech-rate compression), and memory load (sentences virtually doubled in length by the addition of redundant verbiage) would cause children to accept as correct ungrammatical sentences which were missing an obligatory inflection.

The number of errors was predicted to be greatest for the past tense *-ed* sentences, followed closely by the 3rd person singular *-s*, and finally by the plural *-s*. A control condition involving the prepositions *in*, *on*, and *at* was also included, for which ceiling performance was expected for all children. *In* and *on* appear to be acquired relatively early on by children with SLI (Albertini, 1980); in addition, the experiment reported in chapter 5 of this thesis had shown all three prepositions to be robust in a group of 8-12 year old children with SLI.

Finally, the current study included a comparison of sensitivity to inflectional morphemes and phonological sensitivity, as assessed by a phonological discrimination task, in order to explore the possibility that surface features of inflectional morphemes, including their phonological salience, may play a role in their vulnerability to cognitive stress factors.

Method

Participants

138 children were recruited from Years 1 and 2 of local state primary schools. All participants had returned consent forms signed by their parents, agreeing to their participation in the study. All children were monolingual in English, and had no history of hearing, speech, or language impairment, or general education difficulties, according to parental report.

Participants were screened for nonverbal ability (Raven's Progressive Matrices) and vocabulary level (British Picture Vocabulary Scales- long version); criteria for inclusion in the study were age-appropriate scores on both these measures (that is, a score no lower than 85 on the age-standardised scales). A hearing screen (20 dB SPL, at 500, 1000, 2000 and 4000 Hz) was also administered to ensure that there was no peripheral hearing loss, at least at the time of testing. Eighteen children were excluded from the study on the basis of this screen. The profile of the remaining 120 is summarised in Table 6.1.

N = 120	**Range**	**Mean**	**Standard Deviation**
Age (years;months)	5;5 - 7;3	6;4	0;6
Raven's Matrices	96 - 130	120	8.7
BPVS	87-136	108	9.2

Table 6.1: Profile of participants

Stimuli: Grammaticality judgement

Eight sets of 80 sentence stimuli were created to test the effects of sentence speed and length on sensitivity to grammatical inflections. These divided into two versions for each of the following sentence conditions: Short Slow, Short Fast, Long Slow, Long Fast (resulting in eight sentence sets, labelled A, B, C, D, E, F, G, H; see Appendix II for a complete list of sentences, with frequency information).

Within each sentence set, 3 types of grammatical inflection were tested (plural *s*, 3rd person singular *s*, regular past-tense *ed*), with 20 sentences per inflection type. In addition to the inflections, there were also 20 sentences involving prepositions (*in*, *at*, *on*), designed to act as a control condition; a previous study had found ceiling performance on this condition with a group of children with SLI, and it was assumed that 6-year old children with typically-developing language would also find it very easy. Half (10) of the sentences for each inflection-type were well-formed; the other half (10) were ill-formed, such that they were missing an obligatory grammatical inflection (e.g. *We saw two bird in a tree*). The two versions for each sentence condition were created in order to counterbalance across well- and ill-formedness: the sentences that were well-formed in one version would appear in their ill-formed state in the other version.

All sentences were in the active voice, with canonical Subject-Verb-Object word-order. Tense was clearly marked by the opening phrase, which was always either 'Yesterday', 'Last week', 'Every day', or 'Every week'; use of these phrases was counterbalanced across sentences. Plurality was marked where necessary by the use of 'all' or a number (e.g. *two bird, three bear*). To avoid word-position effects, the 'target word' was placed in the centre of the sentence. The overall length of the sentence, as well as the number of phrases, and the number of syllables before and after the target word was counterbalanced across all sentences. Target words were always followed by a vowel, to minimise interference with perception of the word ending (the inflection, or lack thereof). Furthermore, target words were counterbalanced for number of consonant clusters, as this is known to influence lexical processing. Finally, sentences were counterbalanced with respect to the voicing of the target inflection, in order to control for any effect of phonological salience on sensitivity to grammatical inflections. That is, half the plural nouns ended in the /z/ allomorph and half in the /s/ allomorph; similarly for the 3rd person singular verbs, and for the past-tense verbs (/d/ and /t/ allomorphs).

'Long' sentences were created by adding redundant verbiage to their short counterparts. This was mostly done by using a string of adjectives in the subject and object phrases, or by replacing a pronoun or short name with a descriptive phrase or longer names. For example, *Yesterday, we saw two birds in a tall tree* became *Yesterday, my little sister saw two birds in a big, tall, leafy pretty green tree.* As far as possible, the syntactic simplicity of the short sentences was maintained in the long, redundant sentences. Long sentences were essentially double the length of short sentences.

'Fast' sentences were created by compressing duplicates of the 'slow' (i.e. normal-rate, approximately 225 syllables/minute) sentences to 50% of their original length. This was done using SoundEdit 16 for the Macintosh, with proprietary algorithms that excised redundant information in the 5-20 ms time-range, thus altering the temporal but not spectral profile of the signal.

For details of sentence length in each of the four sentence conditions, see Table 6.2.

Recording and editing

Sentences were spoken at a normal rate by an adult male native speaker of British English, and digitally recorded in a sound proof booth using a Tascam DAT recorder (model DA-P1) and Sennheiser ME65 microphone. The input sampling rate was 44.1 kHz. The stimuli were downloaded to a Macintosh computer via a SONY DAT player (PCM-R300), and converted to wav format using ProTools Software. Two recordings of each sentence were made, and the best exemplar was saved for further editing. Artificial peaks were trimmed where this did not affect the rest of the signal. Stimuli were not peak-to-peak normalised, as this produced distortion in some of the stimuli; however, because there were two exemplars to choose from, the overall amplitude remained consistent across sentences.

	# Syllables before target word	**# Syllables after target word**	**Total # Syllables**	**Length (sec) well-formed**	**Length (sec) ill-formed**
Short Slow	**5.5**	**4.8**	**11.3**	**3.10**	**2.95**
Plural	5.7	4.6	11.3	3.28	3.10
3rd Per Sing	5.4	5.2	11.6	3.06	2.95
Past	5.4	5.0	11.4	2.95	2.85
Prepositions	5.6	4.2	10.8	3.10	2.90
Short Fast	5.5	4.8	11.3	**1.55**	**1.48**
Plural	5.7	4.6	11.3	1.64	1.55
3rd Per Sing	5.4	5.2	11.6	1.53	1.48
Past	5.4	5.0	11.4	1.48	1.42
Prepositions	5.6	4.2	10.8	1.55	1.45
Long Slow	**9.6**	**9.4**	**20.0**	**5.18**	**5.06**
Plural	9.6	9.5	20.1	5.22	5.13
3rd Per Sing	9.6	9.4	20.0	5.12	4.96
Past	9.6	9.4	20.0	5.11	5.04
Prepositions	9.6	9.4	20.0	5.28	5.09
Long Fast	9.6	9.4	20.0	**2.59**	**2.52**
Plural	9.6	9.5	20.1	2.61	2.56
3rd Per Sing	9.6	9.4	20.0	2.56	2.48
Past	9.6	9.4	20.0	2.56	2.52
Prepositions	9.6	9.4	20.0	2.64	2.54

Table 6.2: Average sentence lengths in different sentence conditions

Stimuli: Phonological discrimination

Digital recordings were made of the stimuli in the Bridgeman & Snowling (1988) phonological discrimination task. This test comprises 60 pairs of words and non-words which differ in their final phonemes, and which are always s/t or ts/st (selected because they are important sounds in English inflectional morphology).

Two versions of this task were created for the current study: normal speech-rate, and compressed (by 50%) speech-rate. Recording and editing procedures, including speech-compression, are identical to those described for the sentence stimuli, with the sole difference that the speaker was female rather than male.

Procedure

Children participated in two half-hour testing sessions, carried out individually in a quiet room at school. In the first session they completed the hearing screen, as well as the Raven's Progressive Matrices and BPVS; these were scored immediately, and if an age-appropriate score was achieved on both of these, they went on to do one version of the Phonological Discrimination test. This was compiled and run using SuperLab. and was presented monaurally on a Dell Latitude laptop computer, over Sennheiser HD45 headphones. In the second testing session children were randomly assigned to one of the four sentence conditions for the grammaticality judgement task; sentence stimuli were presented by a cartoon monster, on a custom-built program. Children then completed the remaining version of the phonological discrimination task. The order of presentation for the two versions of the phonological discrimination tasks was counterbalanced across subjects. In the second testing session the grammaticality judgement task was nearly always presented first, as it was more taxing and time-consuming and children found it considerably easier to do at the beginning of the session.

Both the grammaticality judgement task and the two versions of the phonological discrimination task were presented on the Dell laptop, with stimuli played monaurally over Sennheiser HD45 headphones. The experimenter wore a set of monitor headphones. All trials were initiated by the experimenter.

Over the course of the two sessions, children were rewarded with the opportunity to make a 'sticker picture'. They were given a blank card in the first session, and after every few trials of the grammaticality judgement and discrimination tasks were given a number of coloured stickers to make a picture with ('sticker breaks' never followed incorrect responses). This proved highly motivational.

Results

Design and predictions

The central hypothesis of this experiment was that introducing additional cognitive processing load to a grammaticality judgement task, in the form of either increased speed or increased memory demands, would produce a profile of error in inflectional morphology of the type observed in SLI. Specifically, under increased task demands, the regular past-tense *-ed* ending was expected to pose the most difficulty for children with normally-developing language, the plural *-s* ending to cause the least difficulty, and the third-person singular *-s* ending to be somewhere between the two. A control condition involving prepositions was expected to produce near-ceiling performance.

The speed and length of the sentences were between-subjects variables, and it was hypothesised that performance with short, slow sentences would be near-ceiling, while long, fast sentences would produce the most errors. Performance on short, fast sentences and long, slow sentences was predicted to be intermediate, with no specific predictions about whether speed or length would have the greatest effect.

Group profiles

Children were randomly assigned to sentence conditions, and it is clear that the four groups are well matched on age and nonverbal ability (see Table 6.3). The matching on the vocabulary criterion is less clear-cut, with the Long Fast sentence group in particular having a slightly higher average score than the other groups. This is partially, though not entirely, attributable to two high-scoring outliers in this group (with age-standardised scores on BPVS of 132 and 136).

Mean (SD)	**Short Slow**	**Short Fast**	**Long Slow**	**Long Fast**
Age (years;months)	6;3 (0;6)	6;4 (0;6)	6;3 (0;5)	6;6 (0;4)
Raven's Matrices	119.8 (8.6)	119.0 (8.6)	120.1 (9.8)	123.3 (7.6)
BPVS	109.9 (7.8)	105.0 (9.4)	105.9 (8.2)	112.9 (9.5)

Table 6.3: Group means and standard deviations for different sentence conditions, on age, nonverbal ability, and vocabulary level.

Data reduction

Data were analysed using the A' measure described in chapter 5. As before, an arcsine transformation was carried out to ensure equality of variances, and all analyses reported use the transformed data. However, for the sake of clarity, graphs show untransformed data.

Overview of data

Figure 6.1 depicts the mean A' scores for the different inflections, in each of the four sentence conditions.

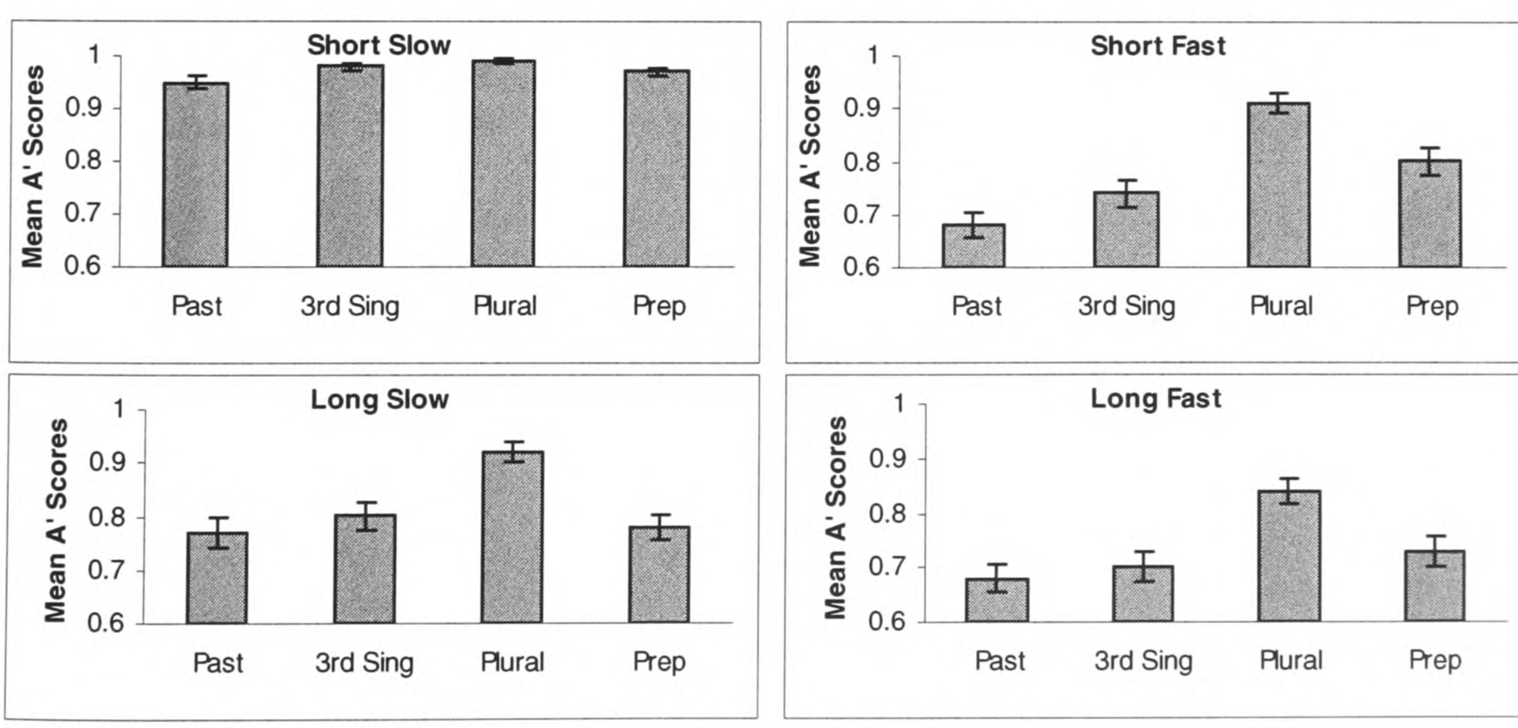


Figure 6.1: Mean A' Scores and standard error bars for each of the inflection types (separate bars) in each of the four sentence conditions (separate graphs).

An initial examination of Figure 6.1 clearly shows that, in all sentence conditions, performance on plurals was best, followed by 3rd person singular, followed by past tense. Performance on the prepositions (control condition) was, contrary to experimental prediction, at roughly the level of 3rd person singular.

The same data are presented in a different way in Figure 6.2, to illustrate more clearly the effects of sentence speed and length on each inflection type. Overall, the Short Slow sentence condition elicited the best performance, while the worst performance was in the Long Fast condition. Short Fast and Long Slow sentences were intermediate, though of these two, there appeared to be better performance in the Long Slow sentence condition.

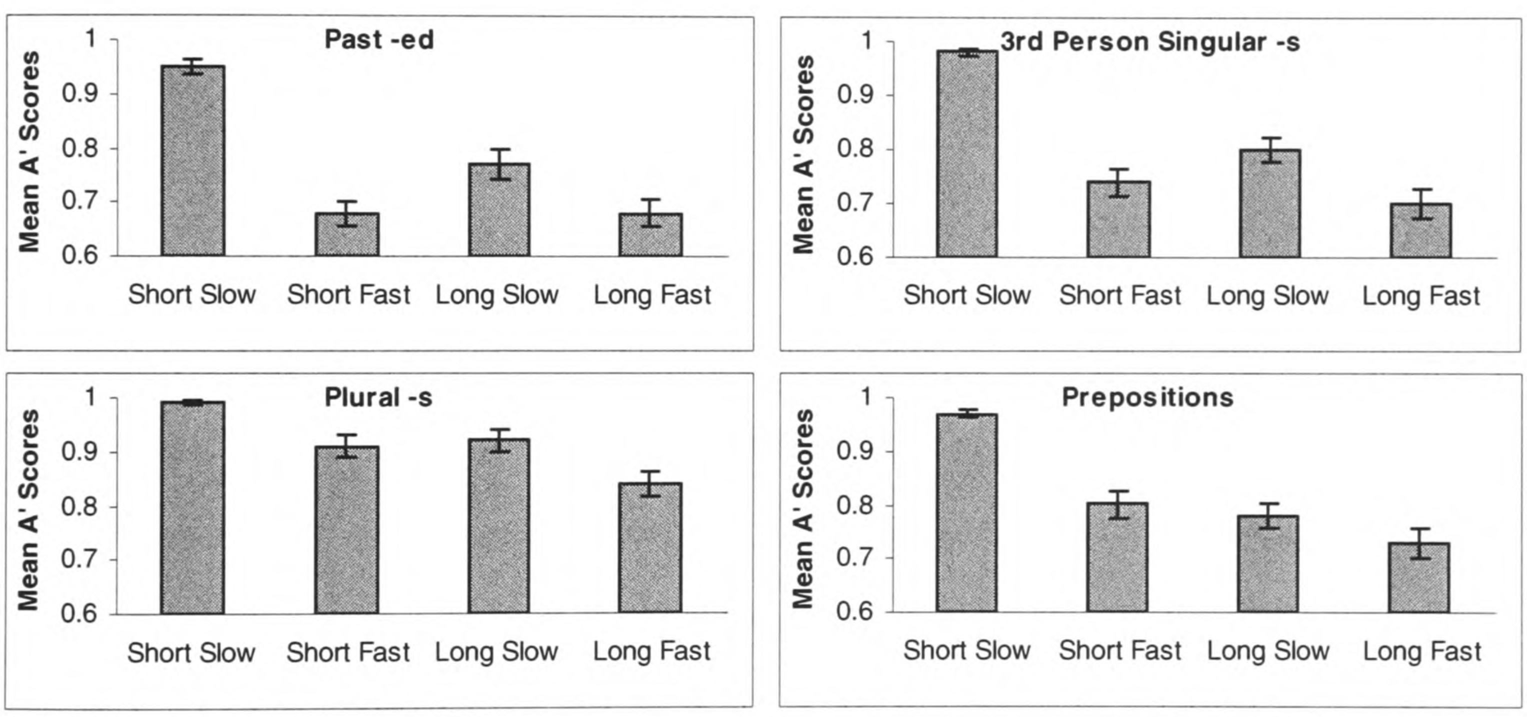


Figure 6.2: Mean A' Scores and standard error bars for each of the sentence conditions (separate bars) in each of the four inflection types (separate graphs).

Within inflectional types, both plurals and prepositions seem to have been equally affected by speed and length; Short Fast and Long Slow sentences produced similar levels of performance. 3rd person singular and past tense seem to have been more affected by speed than length; there were lower A' scores for these inflection types in the Short Fast than in the Long Slow sentences. In fact, for 3rd person singular and past tense, performance in the Short Fast condition appears to be almost identical to the Long Fast condition. This may explain why there appear to be slightly more lower A' scores overall in the Short Fast than the Long Slow condition; it also appears that the past tense inflection was the most vulnerable to this particular cognitive load.

Statistical analysis

A 2 (speed) x 2 (length) x 4 (inflection type) mixed analysis of variance confirmed many of these observations. Between-subjects factors were sentence speed (slow or fast) and sentence length (short or long); the within-subjects factor was inflection type (plural, 3rd person singular, past, prepositions).

There were significant main effects for all three factors: speed [F (1,116) = 105.24, $p < .001$], length [F (1,116) = 63.90, $p < .001$], inflection type [F (2.58,299.24) = 68.70, $p < .001$].

In addition to the main effects, there were several significant interactions: inflection type x speed [F (2.58,299.24) = 5.16, $p < .01$], and length x speed [F (1.116) = 24.62, $p < .001$]. Note that there was no significant interaction between inflection type and length [F (2.58,299.24) = 1.52, $p > .05$]. Finally, there was a significant 3-way interaction between inflection type, speed, and length [F (2.58,299.24) = 7.28, $p < .001$].

Inflection type x speed interaction

The interaction between inflection type and speed is illustrated in Figure 6.3. What is apparent from the figure is that the 3rd person singular and past tense inflections were affected by speed considerably more than the plural *-s* and the prepositions.

A series of 2-way mixed analyses of variance were carried out, to clarify what was driving the inflection type x speed interaction. The between-subjects factor was speed, the within-subjects factor inflection type, examining two inflections at a time.

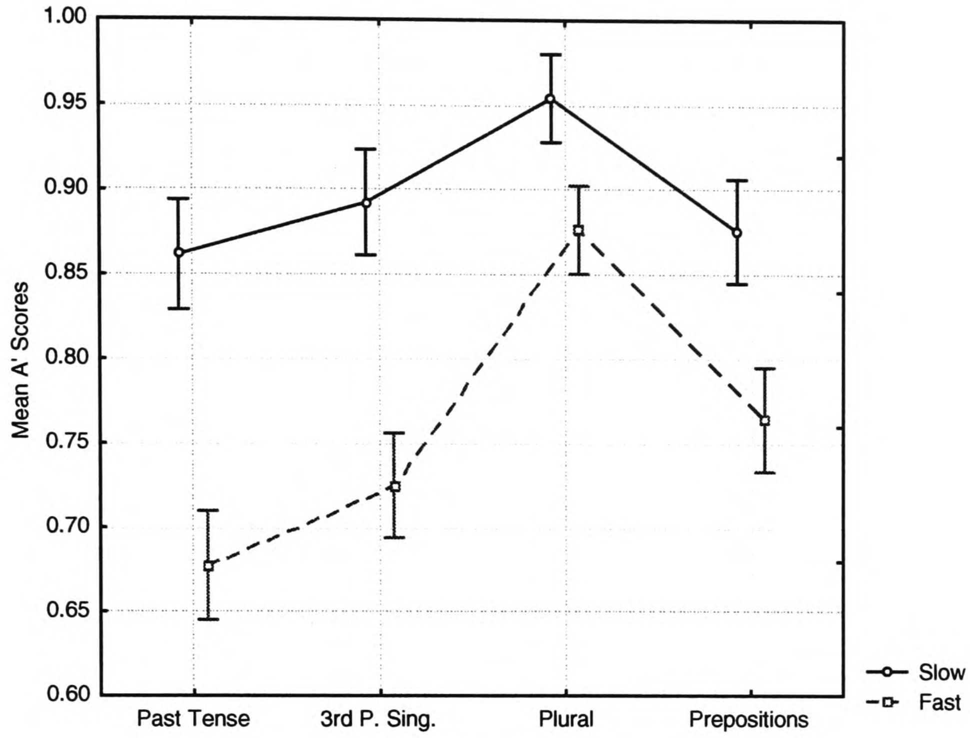


Figure 6.3: Inflection type x speed interaction

The pattern of results suggests that the plural and prepositions were influenced in a similar way by speed: although there were main effects of inflection type [F (1,118) = 59.10, $p < .001$] and speed [F (1,118) = 36.80, $p < .001$], there was no significant inflection type x speed interaction when only plurals and prepositions were included in the analysis [F (1,118) = 0.03, $p > .05$].

The 3rd person singular and past tense inflections seemed to be behaving in a similar way to each other as well, under the influence of speed: here too there were main effects of inflection type [F (1,118) = 18.06, $p < .001$] and speed [F (1,118) = 69.69, $p < .001$], but no interaction [F (1,118) = 0.10, $p > .05$].

In contrast, there were strong interactions of inflection type x speed when the plural inflection was compared to either the 3rd person singular [F (1,118) = 9.46, $p < .01$] or the past tense [F (1,118) = 6.14, $p < .05$]. Similarly, the inflection type x speed interaction was also significant when the prepositions were compared to either the 3rd person singular [F (1,118) = 8.84, $p < .01$] or the past tense [F (1,118) = 6.58, $p < .05$].

Finally, note that there was no main effect of inflection type when comparing 3rd person singular to prepositions [F (1,118) = 0.18, p > .05], suggesting that although they were differently affected by speed, the number of errors made in both these sentence-types was very similar. This is in contrast to every other comparison, in which the main effect of inflection was always significant.

The grouping of plural with prepositions and past with 3rd person singular was also supported by a planned comparison [F (1,116) = 108.04, p < .001].

Inflection type x speed x length interaction

The three-way interaction between inflection type, speed, and length is illustrated in Figure 6.4.

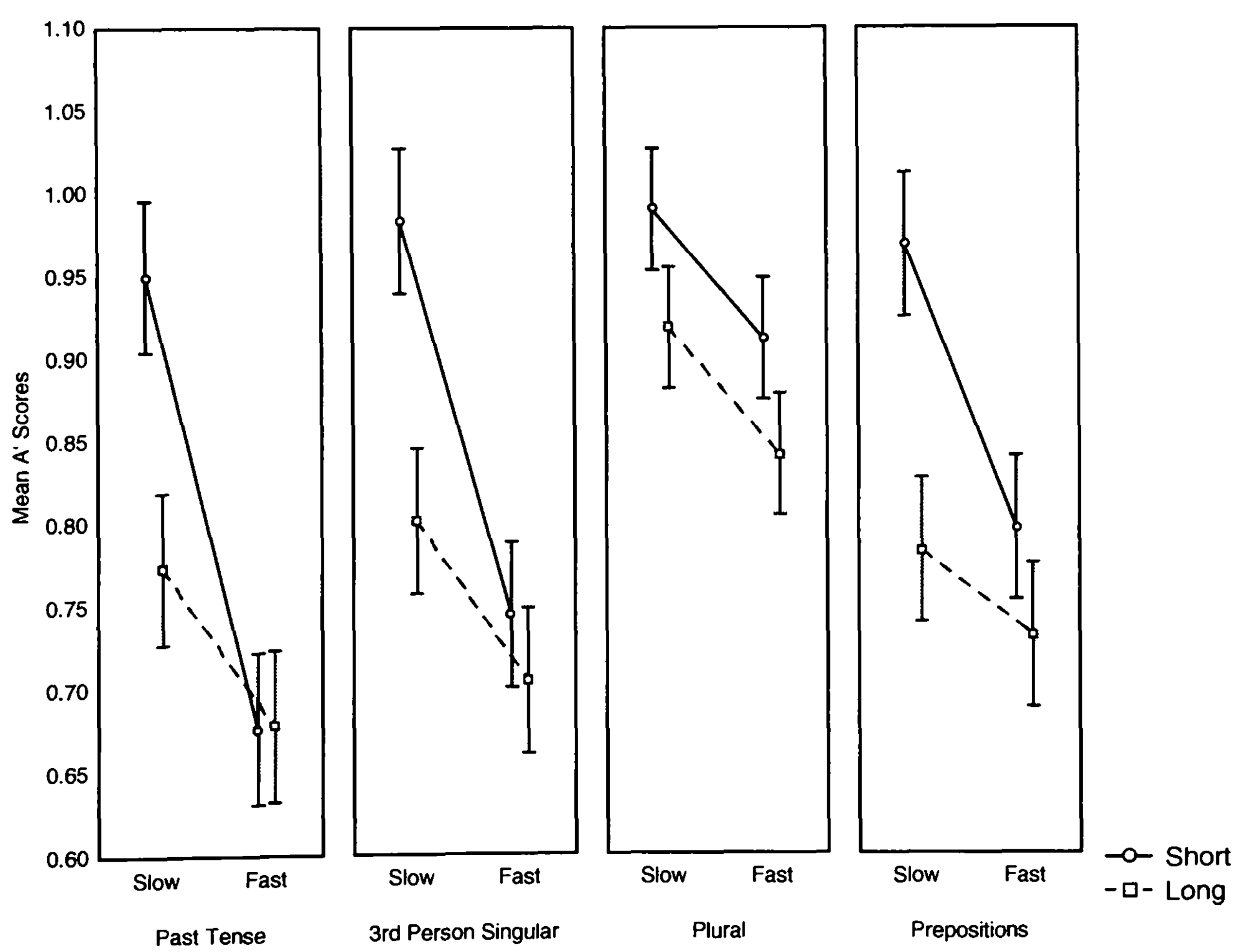


Figure 6.4: Inflection type x speed x length interaction.

This three-way interaction appears to be due to the fact that for every type of inflection apart from the plural, there was an interaction of speed with length such that in the low speed condition, length had great impact (substantially decreasing A' scores), but that in the high speed condition the effect of length was negligible.

This interpretation is supported by a series of four 2 (speed) x 2 (length) analyses of variance, one for each inflection type. These confirmed a significant interaction between speed and length for prepositions [F (1,116) = 14.80, p < .001], 3rd person singular [F (1,116) = 29.41, p < .001], and past tense [F (1,116) = 25.68, p < .001], but not for plural [F (1,116) = 0.19, p > .05].

Further, looking within the long sentence conditions only, there was no significant inflection type by speed interaction [F (2.53,146.73) = 1.23, p > .05]. That is, all four inflection types reacted similarly to speed when the sentences were long, although the actual level of performance differed between inflection types. When the sentences were short, however, there was more variability in the way speed affected different inflections; this was reflected in a significant inflection type by speed interaction [F (2.57,148.96) = 12.70, p < .001].

Effect of allomorph voicing

The results of the study reported in chapter 5 of this thesis suggested that detection of a missing obligatory inflection would not be influenced by the specific allomorph used, at least in the case of the past tense *-ed* inflection. This finding was confirmed in the current study, as there was no effect of voicing on grammaticality judgement scores for the past tense inflection type (that is, no difference for stimuli in which the verb took the /d/ or /t/ allomorph). A 2 (speed) x 2 (length) x 2 (voicing) mixed analysis of variance showed no significant main effect of voicing [F (1,116) = 0.99, p > .05], nor any significant interaction with either speed [F (1,116) = 1.48, p > .05] or length [F (1,116) = 0.08, p > .05].

The equivalent analysis for the /z/ and /s/ plural inflection allomorphs also showed no main effect of voicing [F (1,116) = 1.10, $p > .05$], and no interaction with speed [F (1,116) = 0.20, $p > .05$] or length [F (1,116) = 2.30, $p > .05$].

Somewhat unexpectedly, there was a significant main effect of voicing for the 3rd person singular inflection voicing [F (1,116) = 9.78, $p < .01$], such that stimuli involving the /s/ allomorph elicited more accurate grammaticality judgements than those with the /z/ allomorph. This pattern was consistent across sentence conditions, and there was no significant interaction with either sentence speed [F (1,116) = 0.74, $p > .05$] or length [F (1,116) = 0.05, $p > .05$].

The prepositions condition

The experimental prediction regarding the control condition, which involved the function morphemes *in*, *on*, and *at*, was that they would be robust, and that near-ceiling performance would be maintained across all sentence conditions. This was not the case; averaged across sentence conditions, the mean A' score for prepositions was .82, noticeably lower than the A' of .92 obtained for plurals.

Nor were all three prepositions equivalent: a one-way repeated-measures analysis of variance revealed a main effect of preposition [F (2,232) = 8.55, $p < .001$], and it is apparent from the graph (Figure 6.5) that *in* was considerably more problematic than either *on* or *at*. Pairwise comparisons show that *in* was significantly different from both *on* [*Mean difference* = .21, $p < .001$] and *at* [*Mean difference* = .13, $p < .05$], but that *on* was not significantly different from *at* [*Mean difference* = .08, $p > .05$].

This pattern was consistent when looking at different sentence conditions (figure 6.5). A mixed 2 (speed) x 2 (length) x 3 (preposition) analysis of variance confirmed that there was no significant interaction between preposition and speed [F (2,232) = 0.93, $p > .05$], or between preposition and length [F (2,232) = 1.66, $p > .05$].

Although *in* was consistently more problematic than *on* or *at*, it should be noted that none of these prepositions elicited the ceiling performance that had been predicted for them.

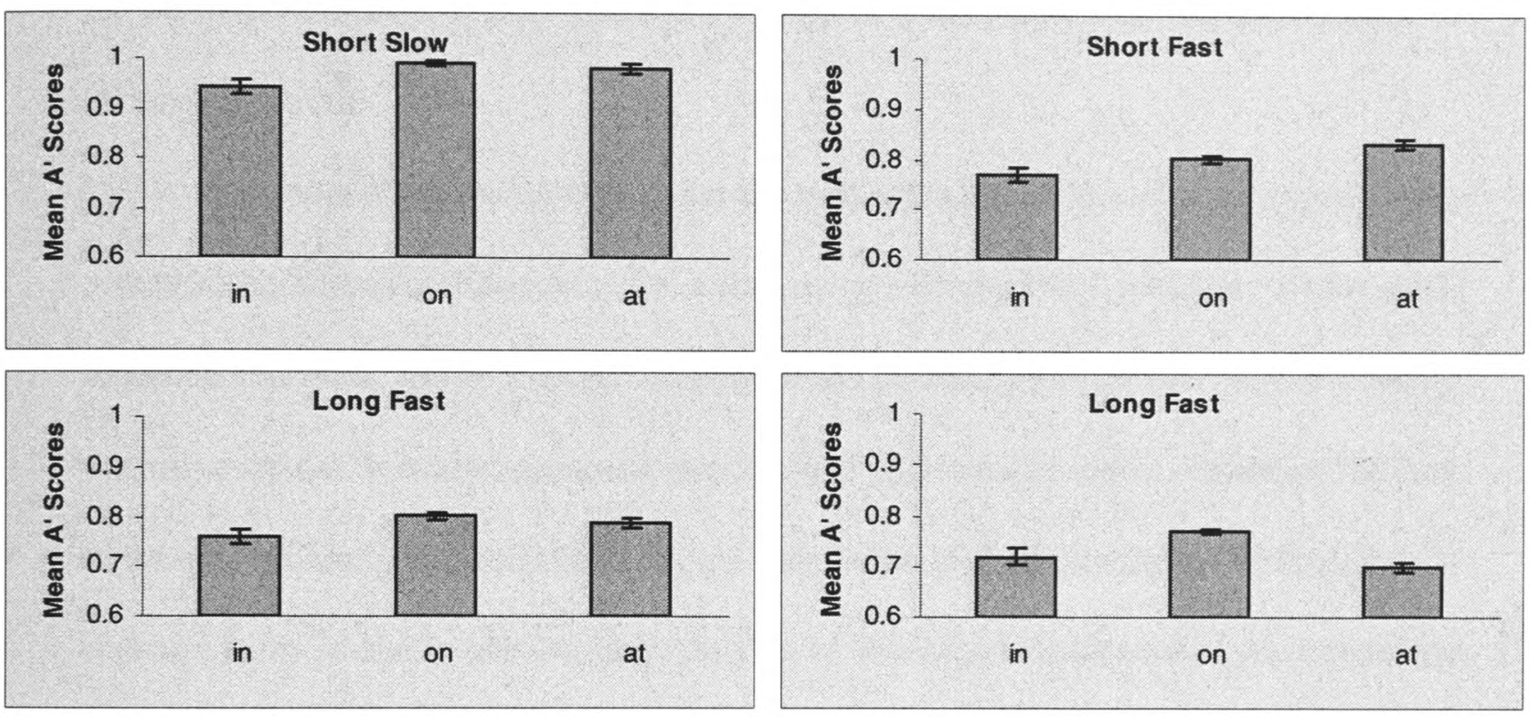


Figure 6.5: A' scores for the prepositions *in*, *on*, and *at* (separate bars) across the four sentence conditions (separate graphs).

Relationship between grammaticality judgement and phonological discrimination

In chapter 5, a very strong correlation was reported between performance on a phonological discrimination task (Bridgeman & Snowling, 1988), and performance on the grammaticality judgement task. This correlation was not replicated in the current study with the normal speech-rate version of the phonological discrimination task [r_s (120) = .05, $p > .05$]; this is clearly due to a ceiling effect, as mean performance on the phonological discrimination task was $M = 58.48$ ($SD = 2.12$) out of a perfect score of 60.

However, a significant correlation was found between the compressed speech-rate version of the phonological discrimination task and grammaticality judgement [r_s (120) = .25, $p < .01$]. This correlation was not attributable to outliers, as it remained significant even when all scores less than 50 were removed (*n* = 5). Overall performance on this version was also high (*M* = 57.68, *SD* = 3.30), but the range of scores obtained was broader: lowest score of 38 compared to lowest score of 48 on the normal-rate version of the task. This suggests that compression of the stimuli in the phonological discrimination task made the level of difficulty more appropriate to the participants, moving performance away from ceiling and enabling correlations to become apparent.

It is clear from the table 6.3 that the bulk of the correlation was carried by the 'stressed' sentence conditions. An exploratory correlational analysis within each sentence condition shows that the strength of the correlation increased with increasing cognitive stress. It is also apparent that the verb inflections, and in particular the past tense *-ed*, generally showed the strongest correlation with phonological discrimination scores. Both of these patterns may be due to the effect described in the preceding paragraph; that is, that while performance was very close to ceiling in the Short Slow sentence condition, as the sentences became longer and faster, children's performance began to deteriorate and there was greater variability in A' scores. Similarly, within inflection types, past tense *-ed* was the most vulnerable and elicited a broad range of performance. This would then allow any correlation which had previously been masked by ceiling effects to emerge.

n = 30	**Short Slow**	**Short Fast**	**Long Slow**	**Long Fast**
Total A'	.21	**.41**	**.41**	**.47***
Past tense A'	.15	.23	**.38**	**.55***
3rd P. Sing. A'	.14	.31	.32	**.37**
Plural A'	.26	.32	.18	.33
Prepositions A'	.00	.30	.22	.28

Table 6.3: Spearman's correlation coefficients between scores on the compressed version of the phonological discrimination task and A' scores on the grammaticality judgement task, for the four sentence conditions (different columns). Bold indicates significance at the .05 level; an asterisk indicates significance at the .01 level.

This pattern of correlations confirms the observation made in chapter 5, in which the grammaticality judgement task tested only sensitivity to past tense *-ed* and prepositions. The very strong correlation between these and phonological discrimination (presented at a normal speech-rate) was carried almost entirely by the past tense items [r_s (23) = .73, $p < .001$]. The noticeably stronger correlation in chapter 5 compared to the current study may be attributable to the wider spread of scores in both tasks, and the lower average scores particularly in the SLI group (phonological discrimination SLI $M = 46.9$, $SD = 9.8$; Control $M = 56.4$, $SD = 3.6$).

Also consistent with the findings reported in chapter 5 is the fact that the current correlation between grammaticality judgement and phonological discrimination (compressed speech-rate) remained significant even when partialling out the factors of age [pr (117) = .23, $p < .01$], BPVS score [pr (117) = .23, $p < .01$], or both [pr (116) = .21, $p < .05$].

Age effects

There was no overall effect of age on performance on the grammaticality judgement task [r_s (120) = .11, $p > .05$]. However, on closer examination it became apparent that there was a very strong effect of age on grammaticality judgement scores (such that older children had higher A' scores) for slow but not fast sentences. The correlation between age and total A' scores was striking for both Short Slow [r_s (30) = .60, p < .001] and Long Slow [r_s (30) = .58, p < .001] sentences, but was non-significant for Short Fast [r_s (30) = .15, p > .05] and was moderate Long Fast sentences [r_s (30) = .37, p < .05].

Although there were no specific a priori predictions about how age and grammaticality judgement scores would be related, it was anticipated that in general older children would have better scores, and that this relationship would be strengthened in the more stressful sentence conditions. These expectations were only partially fulfilled. The dissociation between the effects of sentence speed and length is particularly interesting: since of the two stressors, speed appeared to induce more errors, one might have predicted that children in the speeded sentence conditions would have benefited more from age effects. The reverse pattern was seen; one possibility is that a kind of floor effect was present, such that speeded sentences made the task so difficult that the beneficial effects of age were not strong enough to compensate.

Effect of vocabulary size on grammaticality judgement

As mentioned in the description of the participants, the group of children who were presented with the Long Fast sentence condition had a higher mean BPVS score than the other three groups. In order to ensure that the results of the grammaticality judgement task were not affected by this imbalance, the groups were trimmed to equalise mean BPVS scores (13 outlying BPVS scores identified). The 2 (speed) x 2 (length) x 4 (inflection type) analysis of variance was re-run, and the pattern of results was found to be largely unchanged. The main effect of inflection remained significant [F (2.65,273.13) = 44.42, $p < .001$], as did the interaction between inflection type and speed [F (2.65,273.13) = 5.44, $p < .01$] and that between inflection type, speed, and length [F (2.65,273.13) = 4.52, $p < .01$].

A final observation relating to BPVS may be of interest in comparing the relative effects of sentence speed and length. The correlation between BPVS scores and a total A' measure of grammaticality judgement seemed to be linked to sentence speed more than to sentence length. This correlation was striking for both Short Fast [r_s (30) = .48, $p < .01$] and Long Fast [r_s (30) = .57, $p < .001$] sentences, but was non-significant for both Short Slow [r_s (30) = .25, $p > .05$] and Long Slow [r_s (30) = .15, p

> .05] sentences. This was the opposite pattern to that observed for age, and may suggest that a high vocabulary can act as an effective buffer under the speed stressor, but is less effective for length.

Discussion

The finding that a specific profile of linguistic errors associated with SLI can be induced in a group of children with normal linguistic representations, is strong evidence in favour of processing deficit accounts of SLI. The results cannot be attributed to a linguistic deficit; the culprit must therefore be the heavy cognitive processing demand imposed on the children by the speeding and lengthening of the sentence stimuli.

Speed versus length

The relative effects of sentence speed and length on grammaticality judgement performance are interesting to consider. The initial and most obvious observation is that speeding the sentences is more detrimental to performance than lengthening. As Figure 6.2 illustrates, when the two factors are pitted against each other, Short Fast sentences elicit lower A' scores than Long Slow sentences. It is also clear that the effect is not additive, since Long Fast sentences are not that much worse off than Short Fast sentences. This observation is elaborated in the statistically significant three-way interaction between inflection type, speed, and length: here it is apparent that, except for the case of the plural inflection type, length only has a noticeable effect on performance for the Slow sentence conditions. As soon as sentences are speeded up, the effect of length becomes negligible. Thus far the dominance of speed over length as an effective stressor seems fairly clear cut.

Introducing the effects of age and general language level (using the BPVS as an index) complicates the picture a little. One might reasonably expect that being older and having more developed language skills would both improve performance on the grammaticality judgement task. However, neither factor correlates significantly with A' score when the entire sample of 120 children is included in the calculation.

A logical hypothesis to entertain next is that age and vocabulary might only help when the going gets tougher with increased processing demands - after all, performance in the baseline condition (Short Slow) is virtually at ceiling. This does appear to be the case with vocabulary level, since the correlation between BPVS and grammaticality judgement score is striking (in the region of $r = .6$) when only the groups presented with fast sentence conditions are examined. However, the situation with age is diametrically opposite: the correlation between age and grammaticality judgement score is important (again in the region of $r = .6$) only when the groups presented with slow sentence conditions are examined. Perhaps the effect of age is weak, so that it is beneficial under normal circumstances, but is swamped by something as overpowering as 50% compressed speech-rate. However, this cannot explain why vocabulary and age are influential at different levels of the factor 'speed'; if there were a continuum of strength for potentially beneficial factors, one would expect to see a strong correlation between BPVS and grammaticality judgement scores in the slow sentence conditions, and a weaker correlation in the fast sentence conditions. This was not the case, and there are no obvious explanations for why age and vocabulary level should have a different pattern of influence on performance. However, with respect to the relative effects of speed and length, it is worth noting that whether or not vocabulary level and age exert any influence on performance depends on the speed of the sentence, and not its length. Speed maintains its position as the dominant factor.

Qualitative versus quantitative accuracy of simulation

The efficacy of sentence speeding or lengthening as a means of inducing an SLI-like pattern of errors is important in itself as demonstrating that a non linguistically specific stress factor can result in a linguistically specific profile of performance. In terms of the findings' pertinence to SLI research, however, it is necessary to examine closely how 'SLI-like' the induced performance actually was. A direct comparison with the results from chapter 5 shows that the Long Slow sentence condition produced A' scores for the past tense condition which very closely paralleled data from children with SLI (compare mean A' = .77 (*SD* = .16) for Long Slow sentences to A' = .77 (*SD* = .04) for the SLI group in chapter 5). By contrast, Short Fast sentences resulted in more errors than the children with SLI in chapter 5 (mean A' = .68 (*SD* = .13)).

On the basis of these comparisons, sentence lengthening appears to produce a more quantitatively accurate simulation of SLI than sentence speeding. Bearing in mind the post-hoc nature of these comparisons, one could tentatively conclude that although speeding clearly does a lot of damage, it seems to be too much. However, there are several points to consider before settling on this conclusion, which bear on the issue of the magnitude of the effect of the stressor. The children in the current experiment, although typically developing and in fact generally above the population mean on both verbal and nonverbal tests, were younger and had a smaller vocabulary than the children with SLI in chapter 5 (mean age of 6;4 as opposed to 10;4 in chapter 5; raw BPVS score of 66 as opposed to 77 in chapter 5). Given that age and vocabulary level seem to have some kind of protective effect on this task, the children with SLI may have a slight advantage because of these factors.

The second point concerns the magnitude of the stress factor itself. The sentence compression used in the current study was 50%. This is a high level of compression and on first presentation is challenging even for adults; however, there is a successful precedent for using this rate in this type of simulation study (Dick et al., 2001), and although they found it difficult, it was not beyond the capabilities of the children who participated in this study. However, it is likely that a less extreme rate of compression would produce more quantitatively appropriate results. This would be an extremely interesting avenue for further exploration; that is, calibrating the compression rate to see at which point performance most closely mirrored that of children with SLI (ideally of comparable age or language level). One could speculate that there exists quite a narrow band where the stressor is mild enough to be quantitatively accurate, but severe enough to produce the differentiation between linguistic types which is necessary for a qualitatively accurate simulation. It would be particularly interesting to see whether the appropriate rate would approximate the generalised cognitive slowing rate of 20% to 30% estimated by Miller et al. (2001) and Kail (1994) respectively.

With regard to the question of a qualitatively appropriate pattern of results, the comparison of speed and length effects is once again of interest. The significant speed by inflection type interaction discussed in the results section reflects the clustering of the verb-phrase inflections (past tense *-ed* and 3rd person singular *-s*) separately from the plural *-s* and prepositions. This grouping is precisely what one would predict based on the literature reporting omissions of these inflections in the spontaneous and elicited speech of children with SLI. The failure of sentence lengthening to produce a similar differentiation supports the notion that of the two stressors, speed is the more efficacious simulator.

As there are only two levels for each of the factors 'speed' and 'length' (slow or fast, short or long) in this study, it is impossible to determine whether it is the nature of the stressor, or the magnitude of stress that it produces, which is responsible for the pattern of results. Had the sentences been quadrupled in length rather than doubled, or had they been compressed by 25% rather than 50%, would the relative effects of speed and length have been the same? If a speed-of-processing deficit is the core cause of SLI, to the exclusion of a working-memory deficit, then speed should always produce a more accurate simulation, and vice-versa.

A more extreme version of a processing deficit account might be that there is no single core cause of SLI, but that any processing deficit - which may be in speed of processing in one child and in working memory in another - will produce a similar profile of impairment because of the specific typology of the language being acquired. In this case one might predict that the degree of stress rather than the nature of a particular stressor, will be the determining factor. In the current study these possibilities are confounded, since the degree of speeding used seems to be more stressful than the degree of lengthening used (despite a conscious attempt to control for this by doubling both speed and length). Once again, these would be interesting issues to try to untangle in further studies.

The -s inflections

A critical part of a processing deficit approach to language impairment is the interaction between the putative processing deficit - regardless of its nature - and the specific features of the language in question. The surface hypothesis (Leonard, 1998), for example, suggests that many inflections in English have low phonetic salience, and that this factor in combination with reduced speed of processing underlies the problems with inflectional morphology described in SLI. The case of plural *-s* versus 3rd person singular *-s* is particularly interesting when contrasting linguistic versus processing deficit accounts of SLI. These two inflections are identical in terms of their phonetic salience, yet it is clear from omission data that plural *-s* is less problematic than 3rd person singular *-s*. The surface feature of phonetic salience alone cannot account for the difference in difficulty, and linguistic theories of SLI have argued from this that linguistic features rather than surface features must therefore be the critical explanatory factor. However, phonetic salience is not the only surface feature that could be involved: frequency of the inflection in the child's linguistic input could also play a major role, and it could be argued that the inflection *-s* is heard far more often in the context of plural nouns than 3rd person singular verbs.

In addition, a processing deficit account does not necessarily exclude the possibility of a role for grammatical features; it just doesn't award them primary causal status. Plural *-s* and 3rd person singular *-s* could be treated differently because the former codes only one feature, whereas the latter codes three: tense, person and number. An individual trying to analyse these two inflections under a heavy cognitive processing load, either extrinsic as in the current simulation study, or intrinsic as (suggested) in the case of SLI, could very reasonably be expected to have greater difficulty with the grammatically complex inflection. The key difference between this perspective and a purely linguistic perspective is that here the grammatical complexity is seen as a feature of the stimulus - initially external to the language learner - and the processing deficit as a feature of the mind interacting with the stimulus. A purely linguistic position, on the other hand, makes little distinction between the form of the stimulus in the environment and its mental representation, assuming a simple and direct mapping between the two.

Returning to the case of the *-s* inflections, the finding in the current study that the two were strongly differentiated as a direct consequence of increasing the processing load is a striking demonstration that a dynamic interaction between processing resources and the complexity (grammatical or surface) of the stimulus can produce the pattern of performance associated with language impairment.

Misbehaving prepositions

One result of this experiment which does not fit in with the predictions is the participants' performance on the prepositions condition. In chapter 5, the performance of the group of children with SLI on a virtually identical set of sentences targeting *in*, *at*, and *on*, was at ceiling (mean A' = .97, *SD* = .05). In the literature examining omissions of morphemes in the speech of children with SLI, none of these prepositions is described as problematic, and there is some evidence that *in* and *on* are acquired relatively early in SLI (Albertini, 1980). It is certainly the case that *in* and *on* are acquired at a very early stage in normal language acquisition: de Villiers & de Villiers (1973) report that two-year olds with a mean MLU of 2.82 were able to use *in* and *on* with over 95% accuracy in obligatory contexts. This report agrees with Brown (1973), who ranks *in* and *on* jointly in second place out of 14 morphemes for which age of acquisition was recorded. There is also recent evidence from infant preferential looking research that children understand the meaning of *on* as early as 15 months of age (Meints, Plunkett, Harris & Dimmock, 2002). When children were shown pictures of objects or animals which were either on or under a table, they looked consistently at the appropriate image when told to (for example) *Look at the cup on the table!*

On the basis of all these findings, it was expected that noticing and reporting a missing preposition would not be problematic for the children taking part in this study, and that performance on these sentences would be near ceiling even under the stressed sentence conditions. This was clearly not the case, as A' scores dropped from .98 in the baseline Short Slow sentence condition, to between .83 and .88 on stressed sentence conditions. The young age of the children, cannot account for this drop in performance, given the extremely early age of acquisition of these prepositions. Note that the results did not change when the data for *at* was excluded, to eliminate the possibility that it has a later age of acquisition, since *at* was not one of the morphemes examined by Brown (1973) and de Villiers & de Villiers (1973).

One possibility that may explain the poor performance on the preposition sentences in this study is that they required a shift in strategy: all the other sentences targeted bound morphemes and demanded a focus of attention on the end of a word. Since sentence presentation was randomised and children did not know when to expect a prepositions sentence, it seems likely that they were simply not focusing on the right bit of the sentence, particularly under stressful task conditions. However, the stressful sentence manipulations were intended to simulate what happens every time a child with SLI encounters language; the fact that the children with SLI in chapter 5 did not have any difficulty with the prepositions sentences while the children in the current study did, weakens the argument that this is a convincing simulation of SLI, even within the narrow field of functional morphology. Insofar as the purpose of including a control condition was to demonstrate that increasing task demands did not damage performance across the board, prepositions failed to demonstrate this. However, the robustness of the plural *-s* inflection served the same purpose and created the requisite differentiation in performance for different inflection types.

Finally, within the confines of the three inflectional morphemes examined - past tense *-ed*, 3rd person singular *-s*, and plural *-s* - the manipulation of the speed and length of sentences was effective in simulating an SLI-like profile of performance. Specifically, young children with typically developing language, who could therefore be confidently described as possessing intact linguistic representations of these three morphemes, accepted as grammatical sentences which were lacking these morphemes in an obligatory context to a significantly greater extent when the sentences were speeded or lengthened than when they were not. Furthermore, the gradient of difficulty within the three inflections (verb inflections vulnerable, noun plural inflection robust) is analogous to that seen in the speech of children with SLI. With the proviso that a control condition involving the prepositions *in*, *at*, and *on* did not produce the predicted ceiling level of performance, this could be described as a successful, if highly limited, model of SLI.

Its success strongly supports the notion that global processing deficits - such as speed-of-processing, or verbal working memory - are the proximal cause of SLI and not faulty linguistic representations. However, a model is useful insofar as it illustrates what is possible: the finding that the mechanisms built into a model produce the desired behaviour is not proof in itself that these mechanisms are actually involved in producing this behaviour in people. The current study supports the plausibility of speed-of-processing or working-memory deficits in SLI, but does not demonstrate that they are actually present and causal in the disorder. Such a demonstration would be provided if alleviating processing stress were able to improve the linguistic performance of children with SLI.

Chapter 7: Lightening the processing load

Introduction

If SLI-like error patterns can be induced in typically-developing children by speeding up the language input, it may be possible to induce more typical performance in children with SLI by slowing down the input.

Several studies in the 1970's and early 1980's reported that slowed speech rate improved comprehension in adult subjects with acquired aphasias. Two variables in particular were considered to be potentially important: an overall slowing of the speech signal, and the insertion of pauses in syntactically significant locations. Lasky, Weidner and Johnson (1976) found that both of these factors improved performance in a group of adults with aphasia carrying out a sentence comprehension task. The effect of slower speech rate (slowed to 80% of normal rate) and pauses inserted at phrase boundaries appeared to be independent and additive, although overall slowed speech seemed to have the greater effect. Interestingly, there was no interaction of input manipulation with the syntactic complexity of the sentence: although active affirmative sentences were easier for the adults with aphasia than passives or negatives, it was not the case that slowing the sentence was more helpful when the syntax was more challenging.

Somewhat contrary results were reported by Blumstein, Katz, Goodglass, Shrier and Dworetsky (1985). In addition to overall slowing and insertion of pauses at phrase boundaries, these authors also examined the effects of inserting pauses between each word in the sentence and lengthening the vowels within the words. The only manipulation that improved patients' performance on a comprehension task was the 'syntactic' condition (pause at phrase boundaries), and this only for the six cases of Wernicke's aphasia.

In light of previous evidence it is unclear why this group did not find that overall slowing of the sentences had any effect. One possibility is heterogeneous patient groups; in the Lasky et al. (1976) study, for example, type of aphasia is not specified at all. It may be that speech rate is more important for some types of aphasia than others.

Another possibility is that the actual speech rates used are different across studies. Lasky et al. (1976) defined 'normal' speech rate as 150 words/minute and 'slow' as 120 words/minute (reduction of 20%). Blumstein et al. (1985) on the other hand, define 'normal' rate as 180 words/minute and (in the overall slowing condition) 'slow' as 110 words/minute (reduction of nearly 40%). It may be important to note that in this study speech rates differed across conditions, such that the 'syntactic' condition had a 'slow' rate of only 90 words/minute (reduction of nearly 50%). Therefore it is possible that the improvement in the 'syntactic' condition was not due specifically to easier 'syntactic parsing' but to overall increased processing time. However, 'slow' in Blumstein et al.'s overall slowing condition, was still slower than 'slow' in Lasky et al. Given this variability in rate, it is hard to draw direct comparisons between these two studies.

Manipulation of speech input has also been examined in children with developmental language impairments, at both segmental and suprasegmental levels. One idea that has been fairly thoroughly explored is that rapid changes in the speech signal, such as the formant transitions in stop consonants, are particularly problematic for language-impaired children. A number of studies support the finding that discriminations like /b▶/ /d▶/ /g▶/, which depend on the information contained in the brief formant transitions, are relatively poor in children with SLI and developmental dyslexia, particularly when followed by another acoustic stimulus (Tallal & Piercy, 1974; Tallal et al., 1976; Tallal & Stark, 1981; Leonard et al., 1992).

A corollary of this finding is that lengthening (slowing) rapid transitions may facilitate their perception in language-impaired children. Tallal and Piercy (1975) reported that stretching the duration of consonant formant transitions improved discrimination for place of articulation (and conversely that truncating the steady state portion of vowels diminished discrimination for vowels). Note that similar manipulations in a study with developmental dyslexics (McAnally, Hansen, Cornelissen & Stein, 1997) did not reveal any improvement in performance on a discrimination task.

Nonetheless, a large-scale intervention project, reported initially in Tallal et al (1996) and Merzenich et al. (1996) suggests that intensively training children on altered speech stimuli can have dramatic impact not only on speech perception but also on more general language abilities. In this intervention (Fast ForWord; Scientific Learning Corporation, 1997), the speech signal is expanded by 50%, and the fast (3 to 30Hz) transitional elements are amplified up to 20dB relative to the rest of the signal. The overall effect is to significantly increase the salience of speech elements which are not salient in normal speech; however, since both manipulations are always present in the modified speech, it is difficult to disambiguate the relative influence of lengthening and amplification. Further, the modified speech comprises only part of the overall training program, which also includes training on non-speech stimuli as well as more traditional language-based exercises. It is therefore unclear how much of the reported improvement in children's performance can be directly attributed to slowing of the speech signal.

In a special issue of the American Journal of Speech-Language Pathology Gillam, Loeb and Friel-Patti (2001) concluded, on the basis of a number of case studies, that there was a small but inconsistent improvement in standardised language tests and spontaneous language use after training with Fast ForWord. Further, any improvement in language performance could not be attributed to improved processing of brief and rapid sounds, as claimed, because there was no reliable relationship between improvement on the sound discrimination tasks and improvement on the language measures.

A separate examination of the effects of manipulating speech rate has been pursued by Ellis Weismer and colleagues (Ellis Weismer & Hesketh, 1993; Ellis Weismer & Hesketh, 1996) who looked at the effects of speech rate on language *learning* rather than *processing*. This is a different approach to that reported both in the adult aphasia literature and also in the small number of early studies of children with learning impairments or acquired aphasias, in which slower rates of speech were found to improve sentence comprehension (McCroskey & Thompson, 1973; Campbell & McNeil, 1985).

In Ellis Weismer and Hesketh (1996) children with SLI and mental-age controls were presented with a novel word learning task, in which they learned the 'outerspace' names of toys belonging to Sam the 'outerspace man'. The utterances in which the novel words were introduced were presented at either slow (2.8 syllables/second), normal (4.4 syllables/second) or fast (5.9 syllables/second) speaking rates. There were four types of trials in the task: exposure trials, in which the toy was named (at either slow, normal, or fast rates); production probes, in which children responded to the question "What's this called?" for each toy; comprehension probes, in which children placed Sam next to the named toy; and recognition probes , in which children heard either the label of a particular toy or a phonetically similar or phonetically dissimilar foil, and pressed a button to indicate whether the name was right or wrong. Both accuracy and reaction time were measured for recognition probes.

In terms of the comprehension measure, children with SLI were no worse than language-matched controls, although not as good as mental-age matched controls. However, there was no effect of speaking rate on the comprehension scores. Similarly, speaking rate had no effect on either accuracy or response time measures in the recognition probes. The only strong effect of speaking rate was seen in the production probe, in which children with SLI were significantly worse than either mental-age matched or vocabulary-matched controls in the fast speaking rate condition. The authors interpret this finding within the framework of the capacity theory (Just & Carpenter, 1992), suggesting that production was the most cognitively challenging of the three probes and in the fast-rate condition may have exceeded the processing capacity of the children; comprehension and recognition, on the other hand, may have fallen within the children's processing capacity. Alternatively, they offer the suggestion that comprehension and production may be dissociable mechanisms with differing processing constraints.

Contrary to the experimental hypothesis, there seemed to be no benefit of slow speaking rate when looking at the whole group results. However, individual analyses revealed that 6 out of the 16 children with SLI had improved comprehension scores under the slow rate condition, and 8 out of 16 had improved production scores. It is interesting that these groups did not overlap as much as may be expected: only three children showed improvements in both comprehension and production with slow speaking rate. Another way of looking at it is that 11 out 16 children showed improvement in either comprehension or production.

Rice, Buhr and Oetting (1992) also looked at the effect of processing time on novel word learning, by inserting a pause immediately before the target word. These investigators used the Quick Incidental Learning (QUIL) paradigm, in which novel words are introduced to the child in a naturalistic context and with minimal explicit cues. A group of 5-year old children with SLI and age- and language-matched controls watched 15-minute video programs, which consisted of animated stories containing 10 novel words presented in a voice-over narrative. The authors predicted that inserting a 1 second pause before the target words would enhance their salience and consequently their comprehensibility, by making it easier to segment the speech stream and recognise the target items as novel words to be learned. Contrary to prediction, the pause did not improve comprehension of these words in the SLI group, whose performance remained at the same level as that of the language-matched controls. The pause may have been ineffective because the children may not have had difficulties with speech segmentation in the first place. Alternatively, it may be that the pause was unable to add to the salience of the targets because these were stressed open-class content words, and therefore already very salient.

The common observation that a slow speech rate aids language processing in a clinical setting, in both acquired and developmental language disorders, seems to be only partially supported by empirical evidence. It is difficult to reconcile conflicting findings, partly because of the different methodologies used in different studies. For example, both the Ellis Weismer and Hesketh (1996) and the Rice et al. (1992) studies looked at the effect of slowed speech rate on novel word learning, while earlier studies with children and work with adult aphasics looked at comprehension. Had

Ellis Weismer and Rice examined comprehension of familiar words they may have found a very different picture. The fact that Ellis Weismer and Hesketh found that slowed speech helped some of the children in their SLI group while Rice et al. found that inserting a pause was no help to their SLI group (though they did not report individual data), may mean that slowed speech is more helpful than a gap. This conflicts with Blumstein et al.'s (1985) report that a gap but not slowed speech was helpful, which in turn only partially supports Lasky et al.'s (1976) report that both slowed speech and gaps were beneficial. On the other hand, the gaps in Blumstein et al. and Lasky et al. were at syntactic phrase boundaries, while the gaps in Rice immediately preceded the target word and were within its syntactic phrase. This may interfere with processing of the phrase rather than aiding it. Finally, an obvious but important difference between these studies is that both Ellis Weismer and Hesketh and Rice et al. were exploring a developmental disorder, while Blumstein et al. and Lasky et al. were working with adults with an acquired disorder.

Rationale for the current study

It would be worthwhile to try to clarify the relative effects of overall slowing versus an inserted gap on the linguistic performance of children with language impairment. Since the novel word-learning paradigm has had only limited success in illuminating this issue, it may be appropriate to use a different approach, such as grammaticality judgement. This has the added advantage of direct comparison with chapters 5 and 6. Further, inflectional morphemes, which are known to be disproportionately problematic in SLI, and which have low perceptual salience, may yield more information than the relatively salient open-class words used in the word-learning paradigm. It is possible that the added processing time afforded by slowed speech or an added pause will be sufficient to 'draw out' what knowledge of inflectional morphemes language-impaired children have.

Important issues to consider in designing a study to look at this issue are a) the appropriate ratio of speech slowing b) the length of the gap c) the most informative morphemes to use. With respect to speech rate, the studies reviewed so far vary widely in their chosen ratios of expansion: Lasky et al. (1976) achieved beneficial results with 20% slowing, Ellis Weismer & Hesketh (1996) had partial success with 36%, while Blumstein et al. (1985) had no success at 39%, but a good effect at 47% (though this last was in the syntactic gap condition). It may be important to also consider Burleigh (1997) who showed that a 30% expansion of the speech signal significantly increased intelligibility for individuals with central auditory processing difficulties as well as normally-hearing individuals; however increasing the expansion to 50% was actually detrimental to intelligibility.

As regards the length of the gap or pause, Rice et al. (1992) used a 1 second gap (unprofitably), while Blumstein et al. (1985) used a 1 second gap between major phrase boundaries, and 500 ms for minor boundaries (very profitably).

For best comparison with chapters 5 and 6, the possible inflections to use would be the past-tense *-ed*, 3rd person singular *-s*, plural *-s*, and the prepositions *in*, *at* and *on*. The results from chapter 6, as well as the literature on omission of inflections in the speech of children with SLI, suggests that plural *-s* is not particularly problematic and that performance on this is likely to be close to ceiling even in a normal speech-rate condition; therefore it would probably not be very informative. 3rd person singular *-s* seems to behave very similarly to past-tense *-ed*, and therefore looking at one of these two would probably be sufficient: for comparison with chapter 5 as well as the extensive literature on the development of the English regular past-tense, *-ed* seems the better option. The prepositions made a good control in chapter 5 and so it would be useful to include them as a control in this study as well; it would also be useful to clarify their status given their unexpected behaviour in chapter 6.

Method

Participants

Three groups of children were recruited for this study: a language-impaired group, a language-age control group, and a chronological-age control group. Six children with language impairment were recruited from a private school for language-disordered children in London; the rest were recruited through Language Resource Bases attached to state-run mainstream primary or middle schools in Oxfordshire. All children for the control groups attended mainstream state primary schools in Oxfordshire.

All children participated on the basis of written parental consent; all were monolingual in English, and had no history of permanent hearing loss, according to parental report. In addition, all children passed a 20 dB hearing screen at 0.5, 1, 2, and 4 kHz in each ear.

Criteria for inclusion in the SLI group were the same as in previous experiments: Raven's Coloured Progressive Matrices within normal limits (scaled score of 80 or above) and at least one standard deviation below the mean on two out of the following four language measures: BPVS, TROG, Recalling Sentences subtest of the CELF, and nonword repetition (CNRep). Children with evidence of pragmatic difficulties were excluded on the basis of a score below 132 on the Children's Communication Checklist (Bishop, 1998). A phonology screen was administered, but not used as a criterion for inclusion in the study. With one exception, all children were able to correctly pronounce over 70% of the consonants on the screen; one child scored 65%, but as including his data did not affect the data analysis, it was not excluded from final analyses.

Children in the control group had to be within normal limits on Raven's Matrices and all four language measures. Language-age matches were made on the basis of raw score on the BPVS. Chronological-age matches had birthdays within 3 months of each other. Both control groups were matched to the SLI group on scaled scores for Raven's matrices.

The final numbers in the groups were: 18 children in the SLI group, 17 in the language-match control group, and 18 in the chronological-match control group. Table 7.1 gives an overview of the three groups of children participating in this study, including scores on group inclusion and matching criteria.

Mean (SD) *min - max*	**SLI** **n = 18**	**LA Control** **n = 17**	**CA Control** **n = 18**
Age (years;months)	8;8 (1;6) *6;0 - 11;0*	6;4 (1;4) *4;10 - 9;2*	8;6 (1;5) *6;3 - 11;0*
Raven's Matrices	102 (13) *84 - 121*	106 (12) *88-121*	104 (12) *80 - 121*
BPVS (raw)	61 (13) 37 - 78	61 (16) 36 - 91	78 (12) *56 - 106*
BPVS (SS)	82 (12) *48 - 100*	104 (12) *77 - 122*	100 (7) *85 - 116*
TROG (SS)	84 (13) *66 - 109*	113 (12) *96 - 139*	114 (14) *86 - 139*
Recalling Sentences (SS)	73 (14) *55 - 102*	111 (11) *91 - 137*	106 (12) *85 - 126*
Nonword Repetition (SS)	59 (9) *50 - 80*	126 (13) *102 - 141*	116 (10) *100 - 137*

Table 7.1: Minimum, maximum, mean and standard deviation for scores on nonverbal and verbal tests used for inclusion into groups and as criteria for group matching, as well as chronological age. SS refers to scaled scores, with population M = 100, SD = 15.

Stimuli: Grammaticality judgement

The sentence stimuli were very similar to those used in chapter 6, and many of the same sentences were used for both studies. Four sets of 40 sentences each were created, referred to as A, B, C, and D; within each set, 20 sentences tested for the regular past tense inflection *-ed*, and 20 for the prepositions *in*, *on*, and *at*. Half (10) of the sentences each inflection-type were well-formed; the other half (10) were ill-formed, such that they were missing an obligatory grammatical inflection (e.g. *Yesterday, I walk all the way to school*). Sentence sets A & B, and C & D were counterbalanced across well- and ill-formedness: the sentences that were well-formed in one version (A or C) would appear in their ill-formed state in the other version (B or D). Appendix III provides a list of all sentence stimuli used.

All sentences were in the active voice, with canonical Subject-Verb-Object word-order. Tense was clearly marked by the opening phrase, which was always either 'Yesterday' or 'Last week'. To avoid word-position effects, the 'target word' was placed in the centre of the sentence. The overall length of the sentence, as well as the number of phrases, and the number of syllables before and after the target word was counterbalanced across all sentences. Target words were always followed by a vowel, to minimise interference with perception of the word ending (the inflection, or lack thereof). Furthermore, target words were counterbalanced for number of consonant clusters, as this is known to influence lexical processing. Finally, sentences were counterbalanced with respect to the voicing of the target inflection, in order to control for any effect of phonological salience on sensitivity to grammatical inflections. That is, half the past tense verbs ended in the voiced /d/ allomorph and half in the unvoiced /t/ allomorph. Sentences targeting prepositions were balanced as far as possible for *in*, *on*, and *at*.

'Pause' sentences were created for each of the four sets of sentences (A, B, C and D) by excising the natural pause from sentences which had been recorded with a pause following the target word (see *Recording*) and replacing it with 500 ms of silence.

'Slow' sentences were created for each of the four sets of sentences by expanding duplicates of the normal-rate (approximately 225 syllables/minute) sentences by 30% of their original length. This was done using SoundEdit 16 for the Macintosh, with proprietary algorithms that expanded information in the 5-20 ms time-range, thus altering the temporal but not spectral profile of the signal.

This resulted in 16 sets of sentences: for each of sentence sets A, B, C, and D there were NoPause (normal speech-rate, no pause), Pause (normal speech-rate, pause), Slow (slow speech-rate, no pause), and SlowPause (slow speech-rate, pause) versions.

Recording and editing

Each set of sentences was recorded in two sessions, once with a short pause following the target word, and once with no added pause. As far as possible the speaker attempted to avoid phrase final cues of increased amplitude and duration on the last syllable before the pause; sentences were re-recorded if these cues were highly noticeable, but it was impossible to eradicate them altogether. However, the effects of coarticulation meant that an attempt to excise the *-ed* inflection or preposition digitally from sentences recorded without a pause resulted in a very unnatural sound. It was therefore decided that recording sentences with a natural pause was the preferable alternative.

During recording, all sentences were spoken at a normal rate by an adult male native speaker of British English, and digitally recorded in a sound proof booth using a Tascam DAT recorder (model DA-P1) and Sennheiser ME65 microphone. The input sampling rate was 44.1 kHz. The stimuli were downloaded to a Macintosh computer via a SONY DAT player (PCM-R300), and converted to wav format using ProTools Software. Two recordings of each sentence were made, and the best exemplar was saved for further editing. Artificial peaks were trimmed where this did not affect the rest of the signal. Stimuli were not peak-to-peak normalised, as this produced distortion in some of the stimuli; however, because there were two exemplars to choose from, the overall amplitude remained consistent across sentences. Table 7.2 gives stimulus duration for well- and ill-formed versions of sentences, as well as number of syllables before and after the target word, for sentence sets A, B, C and D.

	# Syllables before target	**# Syllables after target**	**Total # Syllables**	**NoPause well-formed/ ill-formed (seconds)**	**Pause well-formed/ ill-formed (seconds)**	**Slow well-formed/ ill-formed (seconds)**	**SlowPause well-formed/ ill-formed (seconds)**
A	**5.38**	**4.82**	**11.20**	**2.91/2.88**	**3.41/3.38**	**3.78/3.74**	**4.43/4.39**
Past	5.20	4.90	11.10	2.82/2.78	3.32/3.28	3.67/3.61	4.32/4.26
Prep.	5.55	4.75	11.30	3.00/2.97	3.50/3.47	3.9/3.86	4.55/4.51
B	**5.38**	**4.82**	**11.20**	**2.92/2.82**	**3.42/3.32**	**3.80/3.67**	**4.45/4.32**
Past	5.20	4.90	11.10	2.79/2.80	3.29/3.30	3.63/3.64	4.28/4.29
Prep.	5.55	4.75	11.30	3.06/2.84	3.56/3.34	3.98/3.69	4.63/4.34
C	**5.52**	**4.72**	**11.25**	**2.83/2.81**	**3.33/3.31**	**3.68/3.65**	**4.33/4.30**
Past	5.25	4.85	11.10	2.79/2.75	3.29/3.25	3.63/3.58	4.28/4.22
Prep.	5.80	4.60	11.40	2.87/2.87	3.37/3.37	3.73/3.73	4.38/4.38
D	**5.52**	**4.72**	**11.25**	**2.86/2.94**	**3.36/3.44**	**3.72/3.82**	**4.37/4.48**
Past	5.25	4.85	11.10	2.80/2.94	3.30/3.44	3.64/3.82	4.29/4.48
Prep.	5.80	4.60	11.40	2.93/2.95	3.43/3.45	3.81/3.84	4.46/4.48

Table 7.2: The number of syllables before and after the target word, the total number of syllables, and the duration in seconds of the well-formed and ill-formed versions of sentences targeting the past tense and prepositions, for sentence sets A, B, C and D.

Procedure

Each child participated in five sessions of approximately 30 minutes each. In the case of children with language impairment, the first session included the Raven's matrices, BPVS, TROG, Recalling Sentences, and CNRep, and the hearing screen. All children who met criteria for inclusion in the SLI group participated in the subsequent four sessions. In the case of children included in the control groups, Raven's Matrices, BPVS, and the hearing screen were included in the first session. If a child met matching criteria, he or she then participated in the following four sessions, and the remaining language tests were carried out in later sessions.

Each of the subsequent sessions included a version of the grammaticality judgement task, such that over the course of the four sessions each child was presented with sentence sets A, B, C, and D, and sentence conditions NoPause, Pause, Slow, and SlowPause. The combination of sentence sets and conditions, as well as the order of presentation was organised by a Latin Squares design, to ensure an even distribution of these across the whole experiment.

The grammaticality judgement task was presented in the context of the 'Bart Simpson game' (Figure 7.1), which was custom-programmed by Dorothy Bishop. This was run on a Dell Latitude laptop computer, attached to a Phillips touch-screen monitor. The child heard sentence stimuli over a set of Sennheiser HD45 headphones, with the volume set at a comfortable listening level. On hearing a sentence, the child was required to indicate 'grammatical' or 'ungrammatical' by touching as quickly as possible an image on the screen marked by a large tick or cross respectively. The tick was next to a picture of the character of Lisa from The Simpsons, while the cross was next to a picture of Maggie. Feedback was incorporated into the game, such that a correct response was recorded by a clipart image bouncing off Bart Simpson's head on one side of the screen into an enclosure where the 'prizes' built up over the course of the session. An incorrect response elicited a loud sigh. This game format proved highly motivational, and was able to sustain children's interest over the course of four sessions.

Within each session, sentences were presented in quasi-randomised order. Each trial was initiated by the experimenter, to ensure that the child's attention was

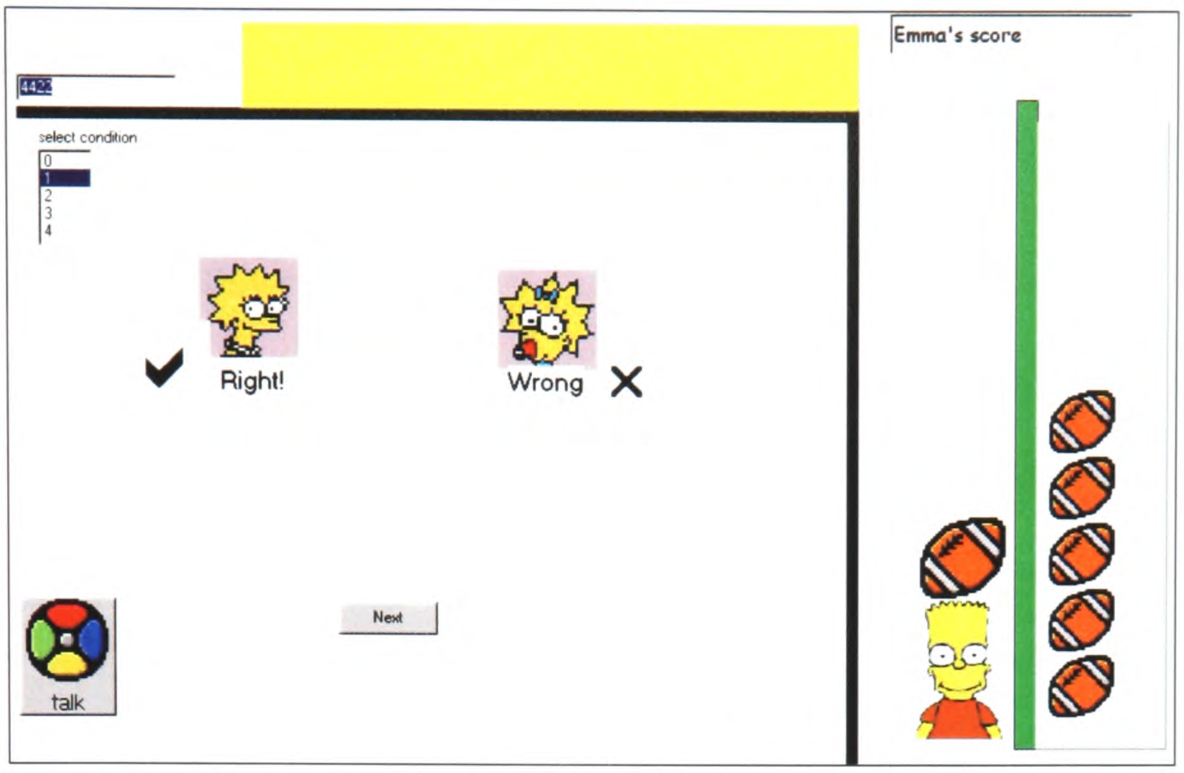


Figure 7.1: The 'Bart Simpson game'.

focused on the task on presentations of the stimulus. All responses, including reaction time data, were automatically recorded in a text file, and extracted for later data analysis. At the start of the first grammaticality judgement session, children's basic button-pressing time was assessed by recording reaction time in a series of approximately ten practice trials, in which the stimulus was 'right' or 'wrong' rather than a sentence.

In addition to the grammaticality judgement task, all children also completed the following measures: phonological discrimination (Bridgeman & Snowling, 1988), digit span (Kaufman, 1983), and past tense elicitation (based on the task reported by Ullman & Gopnik, 1999).

The past tense elicitation task required the child to repeat after the experimenter a sentence such as 'Every day I flap my wings', and then to complete the prompt 'Just like every day, yesterday I ________'. Eight regular, eight irregular, and six nonwords were included in this task; responses were marked as correct or incorrect, and a total score computed for each category.

Results

Design and predictions

The experimental design incorporated a between-subjects factor of group (SLI, CA-Control, LA-Control), and within-subjects factors of sentence speed (normal speech-rate or slowed by 30%), pause (presence or absence of a 500 ms pause following the target word), and inflection type (past tense *-ed*, or prepositions).

The main experimental hypothesis tested in this experiment was that making sentence stimuli easier to process by either reducing the speech-rate (i.e. expanding the sentences by 30%) or introducing a 500 ms pause after the target word would improve children's performance on a grammaticality judgement task. There was no specific prediction regarding the relative effectiveness of sentence slowing or inserting a pause. With respect to group differences, it was anticipated that children with SLI would perform more poorly on the task than both age- and language-matched controls, but that they would also benefit the most from the sentence manipulations. It was also predicted that sentence stimuli testing sensitivity to the regular past tense *-ed* inflection would produce more errors than those testing the prepositions *in*, *on*, and *at*.

Grammaticality judgement accuracy data: Data reduction

As in chapters 5 and 6, accuracy data were analysed using the A' measure. Arcsine transformations were carried out to ensure equality of variances, and all analyses reported use the transformed data. However, for the sake of clarity, graphs show untransformed data.

Overview of accuracy data

It is clear from an initial examination of the data (Figure 7.2) that for both past tense and preposition conditions, the SLI group performed above chance, but below the level of the Language-Age control group, which in turn was below the near-ceiling performance of the Chronological-Age control group. This pattern of group differences was consistent for each of the four sentence conditions (No Pause, Pause, Slow, Slow Pause). In addition, performance on past tense conditions appeared to be worse than that for the preposition condition, most noticeably in the SLI group, though also to a lesser extent in the LA-Control group.

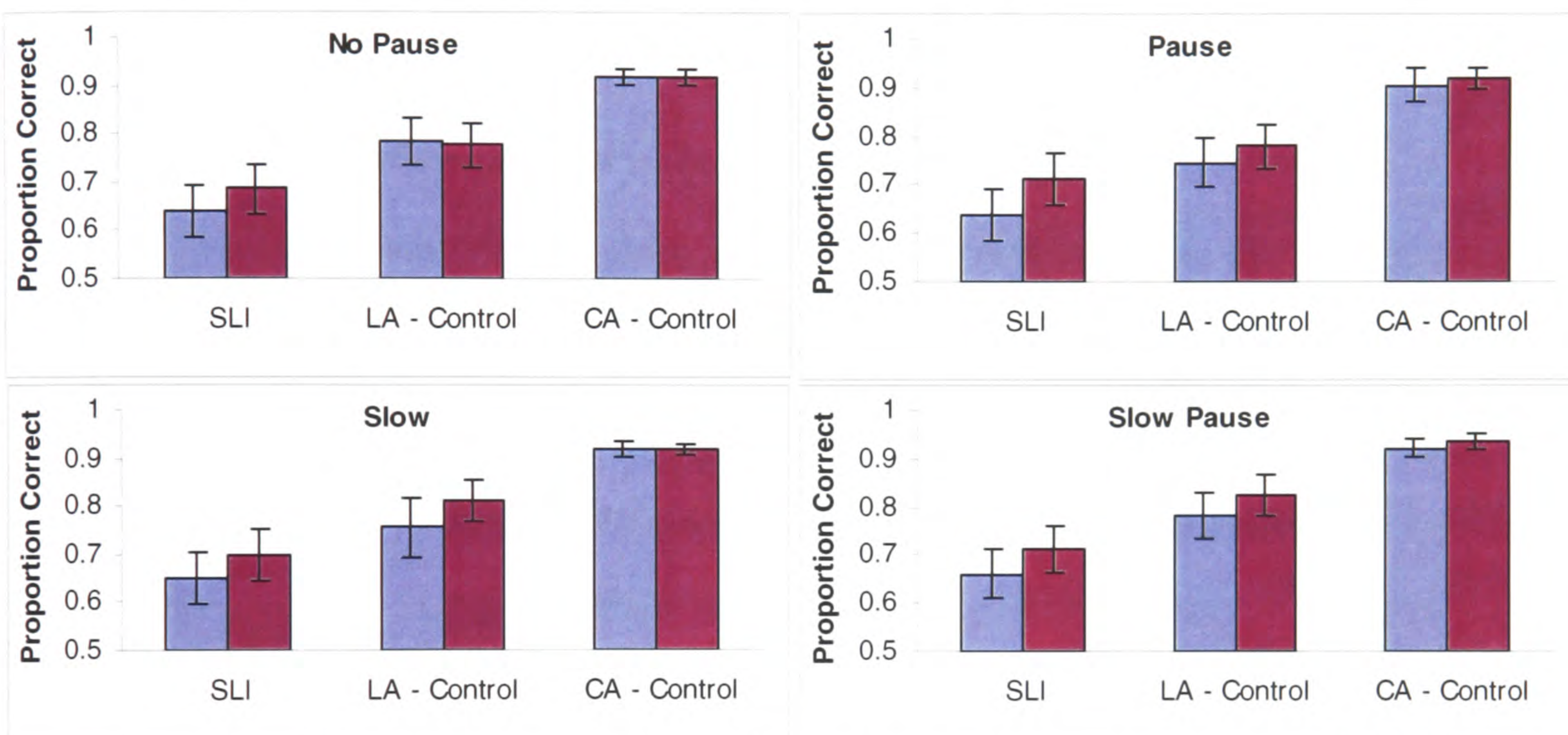


Figure 7.2:. Proportion of correct responses for past tense and preposition sentences, in No Pause, Pause, Slow, and Slow Pause sentence conditions [Blue = past tense, Maroon = prepositions]

For all three experimental groups the overall proportion correct appeared to be fairly similar across sentence conditions (Figure 7.3).

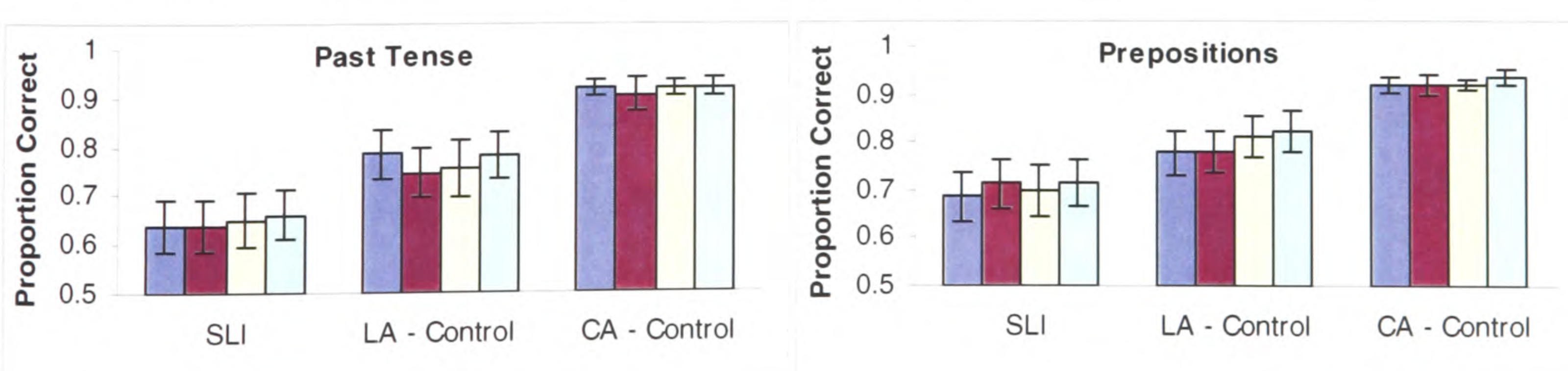


Figure 7.3: Comparison of No Pause, Pause, Slow, and Slow Pause sentence condition, for past tense and prepositions sentences. [Blue = NoPause, Maroon = Pause, Yellow = Slow, Aqua = SlowPause]

Statistical Analysis

A 3 (group) x 2 (speed) x 2 (pause) x 2 (inflection type) mixed analysis of variance confirmed a significant main effect of group [F (2,50) = 10.78, $p < .001$], as well as a significant main effect of inflection type [F (1,50) = 5.17, $p < .05$]. However, and most importantly in terms of the main experimental hypothesis, there was no significant main effect of either sentence speed [F (1,50) = 1.54, $p > .05$] or the presence or absence of a pause [F (1,50) = 0.38, $p > .05$]. That is, neither slowing the speech-rate nor inserting a pause after the target word had any discernible effect on the proportion of correct responses. Finally, there were no significant interactions between any of the four factors (group, speed, pause, inflection type).

The main effect of group was further explored using pairwise comparisons. These showed that while there was a trend for the SLI group to perform more poorly than the LA-Control group, this difference was not significant [*Mean difference* = ..27, $p > .05$]. By contrast, the CA-Control group had significantly better performance than both the SLI group [*Mean difference* = .65, $p < .001$], and the younger LA-Control group [*Mean difference* = .38, $p < .05$].

In separate analyses of variance for the three groups, only the SLI group showed a significant main effect of inflection type [F (1,17) = 6.84, $p < .05$]. That is, the SLI group performed significantly better on the prepositions condition than on the past-tense condition, which is consistent with previous findings described in this thesis, as well as in the wider literature. By contrast, both control groups showed equally good performance on both prepositions and past tense conditions.

Comparison of voiced and unvoiced allomorphs in the past-tense condition

The stimuli in the past-tense condition were balanced for verbs which take the voiced /d/ or unvoiced /t/ allomorph of the regular past-tense inflection. A 3 (group) x 2 (speed) x 2 (pause) x 2 (allomorph) mixed analysis of variance showed no significant main effect of allomorph [F (1,50) = 0.46, $p > .05$]. Nor was there any significant interaction of allomorph with either sentence speed, pause, or group. This pattern of results - that is, no effect of allomorph - remained consistent within all three groups.

Comparison of* in, on, *and* at *in the prepositions condition

The stimuli in the prepositions condition were balanced for use of the prepositions *in*, *on*, and *at*. A 3 (group) x 2 (speed) x 2 (pause) x 3 (preposition) analysis of variance revealed that there was a significant main effect of preposition [F (2,100) = 8.02, $p < .01$]. Since there was no main effect of sentence speed [F (1,50) = 1.12, $p > .05$] or pause [F (1,50) = 1.33, $p > .05$] , and no significant interaction of preposition type with sentence speed [F (2,100) = 0.04, $p > .05$] or pause [F (2,100) = 0.15, $p > .05$], scores were collapsed across sentence conditions to give a single score on each of the three prepositions, for each child. These data are presented in Figure 7.4, which shows that *on* seems to be producing the most correct responses, while *in* and *at* are more problematic.

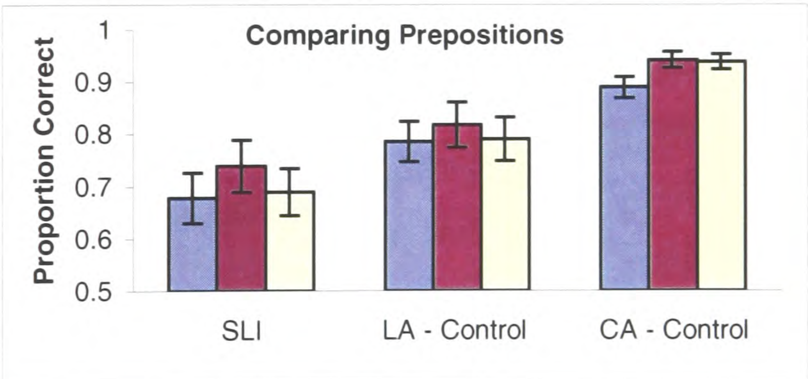


Fig. 7.4: Comparison of proportion correct for the prepositions **in**, **on**, and **at**, for the SLI, LA Control, and CA Control groups. [Blue = *in*, Maroon = *on*, Yellow = *at*]

A series of one-way analyses of variance clarified that the effect of preposition was significant within the SLI [F (2,34) = 4.32, $p < .05$] and CA groups [F (2,34) = 4.52, $p < .05$], but not within the LA group [F (2,32) = 0.85, $p > .05$].

Pairwise comparisons showed that within each of the three groups, no preposition differed significantly from either of the other two. However, there was a strong trend for *on* to produce higher A' scores than *in* for the SLI [*Mean difference* = .19, $p = .05$] and CA groups [*Mean difference* = .28, $p = .06$].

Analysis by order of presentation rather than sentence condition

In terms of the number of errors made by participants, it is clear that the sentence manipulations had no effect on performance. It is possible, however, that a simple effect of practice may have been present, such that performance improved with each of the four sessions that children participated in. An analysis was therefore carried out which included Session Number rather than Sentence Condition; this confirmed what is clear from the graph (Figure 7.5), namely that there was no sign of improvement (or any other consistent difference) over the course of the four sessions. In a 3 (group) x 4 (session number) x 2 (inflection type) analysis of variance, the effect of session number was non-significant [$F\ (3,150) = 0.66$, $p > .05$], nor did session number interact with either inflection type or group.

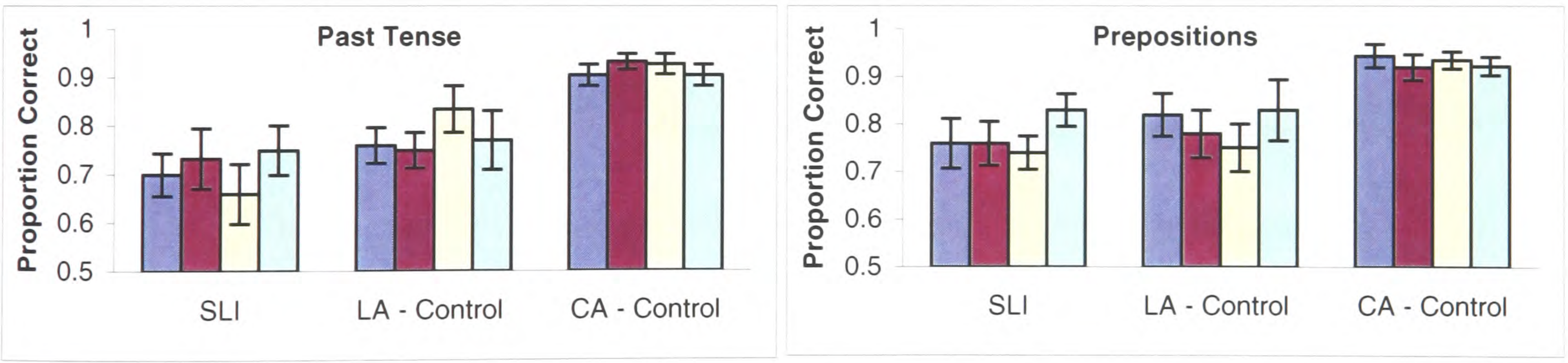


Figure 7.5: Proportion of correct responses across consecutive sessions, for Past Tense and Prepositions. [Blue = Session 1, Maroon = Session 2, Yellow = Session 3, Aqua = Session 4]

Grammaticality judgement reaction time: Data reduction

All raw reaction time data were adjusted for button-pressing time, by subtracting each child's mean button-pressing time obtained in the first session, from each of that child's data points. All further exploration and analysis of the data is based on this adjusted reaction time measure.

Table 7.2 gives the range, mean, and standard deviations for button-pressing time for each of the three groups; it is clear from this that the range of performance in the SLI group approximated that of the chronological-age control group, and was better (faster) than that of the younger controls. A univariate analysis of variance showed a main effect of group [F (2,50) = 9.20, $p < .001$], and pairwise comparisons confirmed that the SLI group mean did not differ significantly from the CA group mean [*Mean difference* = 283.07, $p > .05$], nor from the LA group mean [*Mean difference* = 258.86, $p > .05$], but that the LA group mean was significantly higher (i.e. slower) than the CA group mean [*Mean difference* = 541.93was $p < .001$].

	Minimum	Maximum	Mean	SD
SLI *n = 18*	1493.00	2867.25	2256.34	347.92
LA-Control *n = 17*	1724.00	3353.24	2515.20	437.16
CA-Control *n = 18*	1463.86	2907.88	1973.26	331.72

Table 7.2: Button-pressing time (in milliseconds) for the SLI, LA-Control, and CA-Control groups.

Prior to analysis, the reaction time data for each child was trimmed at 1.5 SD deviations from that child's mean, for each sentence condition. This was done to normalise the data by excluding the long outliers in the right tail of the distribution: 1.5 SD was judged to be an appropriate cutoff point as it eliminated approximately 10% of the data, as recommended by Ratcliffe (1993). A cutoff approach rather than a transformation was used because of the large inter-subject variability. In addition, at least some of the extreme outlying data points were known to be due to procedural difficulties (for instance, many children occasionally failed to touch the icon on the touch-screen at the first attempt, which resulted in very long recorded reaction times); the risk that these outliers reflected valid data therefore seemed low.

The two factors which were explored in the reaction time data are differences in performance between groups, and the speed-accuracy trade-off. This was estimated in terms of the child's response; that is, whether a incorrect response was faster than a correct response, as would be predicted if accuracy were sacrificed for speed. Analyses were carried out separately for the four different sentence conditions, as well as for the two different inflection types, as the data was unadjusted for the varying stimulus lengths.

Overview of the data

It is clear from the graph (Figure 7.6) that reaction times for the different sentence conditions followed the sequence No Pause < Pause < Slow < Slow Pause, which reflects the stimulus lengths in these conditions. There was also a general trend for the SLI group to show longer reaction times than the LA group, which in turn had longer reaction times than the CA group. Bear in mind that these data indicate the time taken for children to reach a decision about the grammaticality of the sentence, and that speed of button-pressing has already been accounted for by subtracting individual baselines for button-pressing. While the children with SLI were fast at pressing the buttons, they seemed to take longer to make a grammaticality judgement.

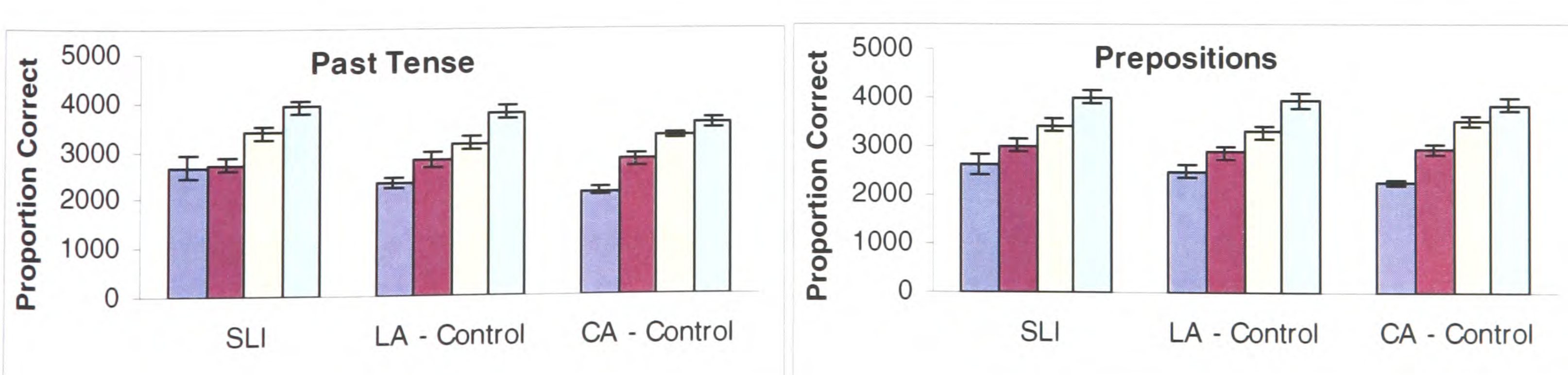


Figure 7.6: Reaction times in the four sentence conditions, for Past Tense and Prepositions. [Blue = NoPause, Maroon = Pause, Yellow = Slow, Aqua = SlowPause]

Statistical analysis

No Pause sentence condition - past tense

A 3 (group) x 2 (response) analysis of variance showed no significant effect of group [F (2,40) = 2.59, $p > .05$]. Nor was there an overall speed-accuracy trade-off, which would have been apparent in a significant main effect of response (i.e. correct and incorrect responses would have differed significantly in reaction time: response [F (1,40) = 1.03, $p > .05$]. Finally, there was no significant interaction between group and response [F (2,40) = 0.60, $p > .05$].

No Pause sentence condition - prepositions

There were no significant main effects or interactions in a 3 (group) x 2 (response) analysis of variance: group [F (2,41) = 1.49, $p > .05$], response [F (1,41) = 2.08, $p > .05$], group x response [F (2,41) = 0.22, $p > .05$].

Pause sentence condition - past tense

In the Pause past tense sentences, there were no significant main effects of group [F (2,37) = 0.28, $p > .05$], or response [F (1,37) = 0.01, $p > .05$], but there was a significant group x response interaction [F (2,37) = 4.49, $p < .05$]. The SLI group had slower incorrect over correct responses, while the LA group showed no difference between correct and incorrect responses, and the CA group had slower correct over incorrect responses.

Pause sentence condition - prepositions

There were no significant main effects or interactions in a 3 (group) x 2 (response) analysis of variance: group [F (2,36) = 1.18, $p > .05$], response [F (1,36) = 1.15, $p > .05$], group x response [F (2,36) = 1.54, $p > .05$].

Slow sentence condition - past tense

There were no significant main effects or interactions in the Slow past tense sentences: group [F (2,37) = 0.24, $p > .05$], response [F (1,37) = 0.98, $p > .05$], group x response [F (2,37) = 0.00, $p > .05$].

Slow sentence condition - prepositions

In the Slow prepositions sentences, there was no significant effect of group [F (2,38) = 0.47, $p > .05$] and no interaction between group and response [F (2,38) = 0.21, $p > .05$]. There was a trend for all three groups to make faster correct responses than incorrect responses, but the main effect of response did not reach significance: [F (1,38) = 3.14, $p > .05$].

Slow Pause sentence condition - past tense

There were no significant effects for the past tense sentences in the Slow Pause sentence condition: group [F (2,38) = 2.58, $p > .05$], response [F (1,38) = 3.16, $p > .05$], group x response [F (2,38) = 1.85, $p > .05$].

Slow Pause sentence condition - prepositions

In the Slow Pause prepositions sentences, although there was no main effect of group [F (2,37) = 0.09, $p > .05$] and no interaction between group and response [F (2,37) = 0.94, $p > .05$], there was a significant main effect of response [F (1,37) = 4.46, $p < .05$], such that for all three groups, correct responses were faster than incorrect responses. This is a stronger, but fundamentally similar pattern to that seen in the Slow prepositions sentences.

Overall, the reaction time data did not reveal any distinct patterns of performance between the three groups, on either past tense or prepositions sentences. It is worth noting that insofar as there were any effects of response in the preceding set of analyses, they tended to show a pattern of faster reaction times for correct responses over incorrect responses, which is the reverse of a speed-accuracy trade-off; the sole exception to this being the CA control group for the past tense in the Pause sentence condition, where incorrect responses were slightly faster than correct responses.

Language and nonverbal measures

By definition, the SLI group performed below the level of both chronological-age and language-age matched controls on the range of standardised language tests administered (Table 7.1), but not on tests of nonverbal ability (Raven's Matrices). Table 7.3 shows group statistics for performance on the phonological discrimination (raw scores) and the digit span tasks. The low performance of the SLI group on phonological discrimination was consistent with performance on other language measures. More surprisingly, the digit span task, although not a language task, was also problematic for the SLI group; this could well be due to its relatively large verbal component.

Mean (SD) *min - max*	**SLI** ***n* = 18**	**LA Control** ***n* = 17**	**CA Control** ***n* = 18**
Phonological Discrimination	49 (10) *26 - 60*	56 (6) *38 - 60*	60 (1) *58 - 60*
Digit Span	7 (2) *3 - 12*	11 (2) *7 - 15*	11 (3) *6 - 15*

Table 7.3: Phonological discrimination and digit span scores (mean, standard deviation, range) for SLI, LA Control and CA Control groups.

In relation to the current study, the main interest of the language measures is in how they relate to the experimental grammaticality judgement task. Correlations are therefore reported between performance on these language measures and the proportion of correct responses on the grammaticality judgement task. The measure used to represent performance on the grammaticality judgement task is a composite of past tense and preposition conditions, as this did not differ appreciably from treating them separately. In view of the analyses reported earlier which showed that responses were indistinguishable between sentence conditions, these have been collapsed into a single score for each child.

	All Groups $n = 53$	**SLI** $n = 18$	**LA Control** $n = 17$	**CA Control** $n = 18$
Raven's	-.03	-.14	.35	-.45
BPVS	**.51***	.34	**.62***	.18
TROG	**.60***	.36	**.78***	.02
Sentence Recall	**.51***	.43	**.71***	-.09
Nonword Rep.	**.45***	.28	.31	.09
Phon. Discrimin.	**.72***	**.81***	**.57**	.28
Digit Span	**.57***	**.78***	**.85***	-.05

Table 7.4: Spearman's correlations between A' scores on the grammaticality judgment task, and scores on language and cognitive measures. Bold indicates significance at the .05 level; an asterisk indicates significance at the .01 level.

It is clear from the values in Table 7.4 that overall, there was a strong relationship between the grammaticality judgement task and the language measures; however, this relationship may have been partly reliant on differences between the 3 groups, since most of the correlations were weaker within the groups. Within the CA group, the negligible size of almost all the correlations was probably due to ceiling performance on the grammaticality judgement task.

It is interesting to note that within the SLI group, the correlations between grammaticality judgement and standardised language scores were only moderate, whereas within the LA group they were strongly significant. By contrast, phonological discrimination and digit span, which tap verbal processes but are not 'language tests' per se, correlated very robustly with grammaticality judgement in both groups. It is also important that there was no significant correlation in any of the groups with nonverbal ability, as assessed by Raven's Matrices.

Finally, when these correlations were explored using reaction time data rather than proportion of correct responses, there were no significant relationships between the grammaticality judgement task and any of the language and nonverbal measures.

Partial correlation: Grammaticality judgement and phonological discrimination

The correlation between grammaticality judgement and phonological discrimination merits further investigation, as it is not only the most striking in the SLI group, but it also confirms findings reported in chapter 5 and 6 of this thesis. Neither the grammaticality judgement task nor the phonological discrimination task were age standardised; a correlation between these with age partialled out remained significant (Table 7.5). Partialling out vocabulary level (BPVS) also left the correlation intact, as did partialling out both age and vocabulary level. The correlation was also not simply attributable to group differences, since it remained strong within the SLI and LA groups. The lack of a significant correlation within the CA group almost certainly reflects ceiling effects on both tasks (although note that one outlier, with a phonological discrimination score of 45, was excluded from this calculation).

	All Groups	**SLI**	**LA Control**	**CA Control**
Age Partialled Out	**.72*** (df = 50)	**.51** (df = 15)	**.75*** (df = 14)	.12 (df = 15)
BPVS (SS) Partialled Out	**.67*** (df = 50)	**.69*** (df = 15)	**.69*** (df = 14)	.02 (df = 15)
Age & BPVS Partialled Out	**.58*** (df = 49)	.37 (df = 14)	**.70*** (df = 13)	.00 (df = 14)

Table 7.5: Partial correlations between proportion of correct responses on the grammaticality judgement task, and score on the phonological discrimination task. Bold values indicate significance at the .05 level; an asterisk indicates significance at the .01 level.

Past tense elicitation

The proportion of correct responses (that is, an appropriate past tense form of the given stem) for regular real verbs, irregular real verbs, and nonwords was compared for the three groups. As is apparent in Figure 7.7, the children with SLI always had fewer correct responses than either the of the control groups, and the LA group also had fewer correct responses than the CA group. Furthermore, performance was best overall on the real regular verbs, followed by nonwords (which were almost always regularised), and lastly real irregular verbs. A 3 (group) x 3 (verb type) analysis of variance confirmed that there were significant main effects of group [F (2,50) = 14.18, $p < .001$] and verb type [F (2,100) = 76.85, $p < .001$], as well as a significant interaction between the two [F (4,100) = 4.90, $p < .01$]. The interaction stemmed from the fact that for real irregulars, the LA group was indistinguishable from the SLI group [t (33) = -0.22, $p > .05$].

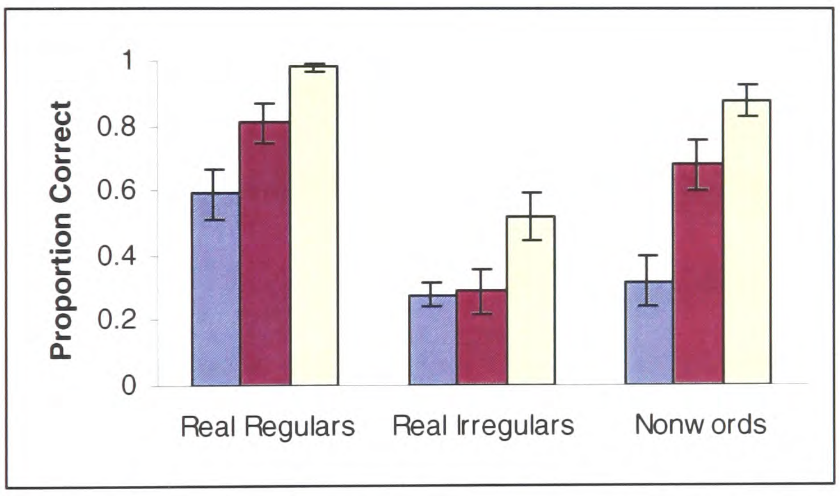


Figure 7.7: Proportion correct on past tense formation for real regular, real irregular, and nonword verb stems.
[Blue = SLI, Maroon = LA Control, Yellow = CA Control]

With reference to the current study, the results of the past tense elicitation task are most interesting in the way they relate to the grammaticality judgement task. For such a comparison, only a subset of the data is useful: the real regular verb condition from the elicitation task, and the past tense inflection type from the judgement task. The correlation between these two measures, when the entire sample is included, is strong [r_s (53) = .44, $p < .01$]; this implies an overlap between the two tasks which may reflect either task-independent knowledge of the past tense, or possibly metalinguistic skills that both tasks call on.

The correlation is probably at least partly attributable to differences between the three groups, as it becomes non-significant (although not negligible) when calculated separately for the three groups: SLI [r_s (18) = .31, $p > .05$], LA [r_s (17) = .24, $p > .05$], CA*.

Age effects

A moderate but significant correlation was obtained between chronological age and performance on the grammaticality judgement task [r_s (53) = .29, $p < .05$]. This effect was most marked within the SLI group [r_s (18) = .55, $p < .05$], and to a lesser extent the CA group [r_s (18) = .46, $p > .05$], while within the LA group it was negligible [r_s (17) = .14, $p > .05$].

Comparison between chapters 5, 6 & 7

Data from the grammaticality judgement task from the three studies reported in chapters 5, 6 and 7 is presented in Table 7.6. Mean group A' scores are shown for past tense and prepositions sentences.

		SLI		**Control**	
Chapter 5	**Past Tense**	.77 (.12)		.97 (.02)	
	Prepositions	.97 (.05)		.96 (.08)	
		Baseline	**Fast**	**Long**	**Fast + Long**
Chapter 6	**Past Tense**	.95 (.07)	.68 (.13)	.77 (.16)	.68 (.13)
	Prepositions	.97 (.04)	.80 (.14)	.78 (.13)	.73 (.14)
		SLI		**LA-Control**	**CA-Control**
Chapter 7	**Past Tense**	.65 (.21)		.77 (.20)	.92 (.07)
	Prepositions	.70 (.20)		.80 (.16)	.92 (.05)

Figure 7.6: A' scores (means and standard deviations) on past tense and prepositions sentences, from the grammaticality judgement data reported in chapters 5, 6, and 7.

One notable comparison is between the SLI groups in chapters 5 and 7, as for both past tense and prepositions, the children with SLI in chapter 5 performed

* Three outliers were removed from the CA group for this calculation; however, as all remaining individuals had scores of 100%, a correlation coefficient could not be calculated.

considerably better than those in chapter 7. One factor that might account for this is the 2 year age difference between these groups (mean age for children in chapter 5 was 10;4, while for chapter 7 it was 8;8). The past tense performance of the children with SLI in chapter 5 was comparable to the group presented with Long sentences in chapter 6, and the younger language-age control group in chapter 7. The SLI group in chapter 7, on the other hand, most closely resembled the groups presented with the Fast sentence conditions in chapter 6. The chronological-age control groups in chapters 5 and 7 performed at the same level as the much younger (6-year-old) children in chapter 6 who were presented with the baseline sentence condition. Finally, although the magnitude of the difference varied between studies and groups, there was a consistent tendency for the prepositions sentences to elicit higher scores than the past tense sentences.

Discussion

The attempt to lighten the processing load by slowing down sentence stimuli or inserting a pause after the target word, did not improve the performance of children with SLI on a grammaticality judgement task. Children - both SLI and controls - were no more likely to reject a sentence rendered ungrammatical by the omission of an obligatory past tense inflection when these sentence manipulations were introduced.

It is possible that this failure was due to the magnitude of the sentence manipulations, that 30% speech-signal expansion and a 500 ms pause were not strong enough aids, and that a greater degree of slowing or a longer pause would have achieved the desired effect. The Fast ForWord training program for instance, which has claimed considerable success, uses a 50% speech-expansion rate. On the other hand, keeping in mind findings which suggest that expansion greater than 30% diminishes intelligibility, it is unlikely that there is a simple linear relationship between speech-rate and language comprehension and analysis. Similarly, it is doubtful whether a longer pause would necessarily be beneficial; it is conceivable that past a certain length it interferes with phonological memory and is actually detrimental. Although 500 ms certainly did not seem to impair performance, it is possible that a shorter pause might be more helpful.

Alternatively, it is possible that the nature of the manipulations was misconceived, and that a different type of manipulation may have improved performance. The focus of the current study was very much based on the idea that the processing load which needed to be alleviated was related to speed of information processing. Slowing the speech-signal was therefore intended to give extra time to analyse every portion of the acoustic signal, possibly at a relatively low level of speech perception; inserting a pause was intended to allow extra time to process, perhaps at a more metalinguistic level, the end of the target word where the inflection (or prepositions) would either appear or fail to appear. However, as discussed in the previous chapter, there is plenty of evidence to suggest that the proximal difficulty may lie elsewhere, with one specific suggestion being phonological working memory. Neither of the sentence manipulations used here was designed to be a memory aid, and it could even be argued that both slowing speech and inserting a pause would exacerbate a short-term memory problem as the phonological material would have to be maintained over a longer period of time.

As the results of the study presented in chapter 6 demonstrated, a high memory load produced SLI-like errors on the grammaticality judgement task, at a level which was even more comparable to data from children with SLI (chapter 5) than sentence speeding. Had the current study aimed to alleviate memory load, a possible change to the task would have been to present a picture matching the sentence at the same time as the auditory stimulus; this may have made comprehension of the sentence easier and released cognitive resources to perform the necessary morphological analysis for the grammaticality judgment. This example is entirely speculative, as there was no evidence of a trade-off between comprehension and grammaticality judgement (there being nothing in the task to control for sentence comprehension). However, it does demonstrate that there are many ways in which the task could have been changed, each of which could have addressed different putative processing stumbling blocks. It is possible that I just chose the wrong stumbling block, or the wrong way to remove it.

An equally plausible explanation, however, is that children with SLI have mental representations of the past tense which are faulty, and that any relatively minor alteration of the cognitive processing demands for a specific task is unlikely to reveal hidden depths of intact inflectional knowledge, because it simply isn't there. This can account for both the lack of improvement in performance across sentence conditions, as well the overall low level of performance in the SLI group. It is not at all implausible that as a group they don't know that *Yesterday I walk all the way to school* is ungrammatical.

Following this straightforward logic, however, suggests that the imperfect performance of the younger language-matched control group is also attributable to faulty linguistic representations; this is a problematic conclusion to reach, as we know that these are children whose language is developing normally. As far as the older chronologically-matched controls are concerned, their virtually perfect performance is a guarantee that at least their representations of the linguistic structures required for the task are beyond reproof.

It may be helpful to turn from the children's linguistic knowledge to the task at hand as an explanation for the less than perfect performance of two out of the three groups. No task, and certainly not the current grammaticality judgement task, can claim to be a direct measure of the state of children's mental representations of linguistic constructions. Therefore A' scores do not directly represent children's knowledge of either past tense *-ed* and prepositions, or when it is appropriate and necessary to use them. They may have perfect knowledge of these things and still fail to score a perfect 1.0, because they aren't paying attention for a couple of items, or because they temporarily forget what they are meant to be listening for, or any number of other prosaic reasons. It follows that one could describe the LA group's performance, for example, as being at ceiling; but that the level of the ceiling is set by children's ability to cope with the performance - including metalinguistic - demands of the task. The older, chronologically matched control children are effectively scoring perfect 1.0's, and so are clearly more than able to cope with task demands. The children with SLI perform poorly, and it's entirely possible that some of their errors are also attributable to difficulty with the task.

However, task demands can only explain overall performance, and not differentiation between conditions within the same task; this is after all the reason for using a control condition. In the present study, the critical comparison is between the past tense and preposition conditions.

In the SLI group, the prepositions are robust relative to the past tense *-ed* inflection; this is precisely the pattern that would be predicted by the Extended Optional Infinitive (EOI) account (Rice et al., 1995; Rice & Wexler, 1996). According to the EOI, SLI is characterised by an immature grammar which allows optionality in the marking of finiteness. Past tense marking is clearly a question of finiteness, and it is a well-known trouble spot in SLI, whereas prepositions are neither related to finiteness nor traditionally problematic. However, although there was a significant mismatch between prepositions and past tense, performance on the prepositions sentences was not at absolute ceiling for the SLI group. One could treat the level of performance for the prepositions as the effective ceiling for this group, and assume that task demands effectively capped the level of the ceiling, as discussed earlier. In fact, this is a necessary assumption for taking an EOI perspective on this data, as otherwise one has to conclude that there is an element of optionality involved in the preposition sentences, which is not consistent with the idea of optionality being restricted to finiteness markers.

Similarly, the less than perfect performance of the younger group on both past tense and prepositions, will have to be attributed to a 'task demand ceiling'; their past tense errors could perhaps have been put down to a normal Optional Infinitive stage (although they're a little old for it, as Wexler (1996) estimates that the OI is normally over by age 5), but there is no equivalent explanation for poor prepositions.

The level of performance of the LA group means we must take seriously the role of task demands - and the implied processing capacity of the individual - as part of the explanation for errors in grammaticality judgement. The discrepancy between past tense and prepositions in the SLI group means that the nature of the grammatical construction must also play a role. In both cases an explanation used for one group must also be applied to the others. Therefore there must be an interaction between task demands - or processing capacity - and the specific grammatical morpheme in question, such that one is more vulnerable than the other, and such that this selective vulnerability is exacerbated in the SLI group.

The EOI, although it encapsulates the pattern of results very neatly, is intended to provide a phenotypic marker for SLI and is primarily descriptive; as such, it does not offer a convincing explanation of why young typically developing, and older children with SLI treat tense as optional. A maturational mechanism is invoked, and the suggestion that "for children with SLI, there may be a problem with the activation of a time-referenced onset switch of some sort in the grammar." (p. 230, Rice & Wexler, 1996). Additionally, the EOI is not described in terms of a deviant grammar, and rejects the idea that there are "'abnormal' or 'missing' principles or structures" (p. 227, Rice & Wexler, 1996). At the same time it rejects the idea of an on-line processing deficit such as the surface account, on the basis that phonetic salience is not sufficient reason for the relative robustness, for example, of plural *-s* versus 3rd person singular *-s*. It is argued that if, for reasons of processing limitation, *-s* was not entered correctly into a morphological paradigm, errors in use should appear randomly; and yet, when 3rd person singular *-s* is used by children with SLI, it is almost always used correctly.

This argument only works if one views linguistic representations and morphological paradigms as black-and-white entities, which are either present or absent, faulty or intact. The picture is very different if they are viewed in greyscale, with infinite gradations between absence and presence, and the possibility (probability) of a correctly specified but weak representation. From this perspective, one would not expect random use of structures, but rather would expect to see correct use some of the time, and omission when processing demands are high. Strongly represented structures would be more robust and less likely to be omitted than weakly represented structures in the face of cognitive stress. Parallel performance would be expected in a receptive task, such as the grammaticality judgement used in the present study. In fact, that is what was seen, with above-chance performance overall, but omission of the weak *-ed* rather than the prepositions when the task demands were too high for on-line processing capacity.

The question of how some structures come to be weakly represented can be parsimoniously laid at the door of a processing deficit in early life; whether the deficit is one of perception, memory, or speed of information processing, it is likely that the linguistic elements that will suffer are those which offer the least information for the highest processing cost (Bates & MacWhinney, 1987; MacWhinney & Bates, 1989). Although many processing accounts of SLI emphasise the on-line processing costs of real-time linguistic analysis, presumably the same deficits are hypothesised to have been present in early childhood and the initial stages of language acquisition. In this case it would be astonishing if children's linguistic representations were able to develop normally and robustly. It is plausible to say, then, that by the time children with SLI reach school-age, their mental representations of certain linguistic structures - such as past tense *-ed* - are less robust than certain other structures - such as prepositions - and that the reason for this is that an early processing deficit disrupted the development of the perceptually and semantically less salient morpheme (*-ed*) more than the development of the more salient morphemes (*in, on, at*).

The question remains as to whether the processing demands of the grammaticality judgement task which were responsible for the level of errors overall, are the same as those which caused the development of weak representations of the past tense but not prepositions in the SLI group. If the two processing challenges are fundamentally the same, then one implication is that the less marked differentiation between past tense and prepositions in the young LA group was only quantitatively different from the SLI group. Had the LA group's performance been at the level of the SLI group, the differentiation between prepositions and past tense might also have been seen in these children with typically developing language. That is, the greater the drain on resources, the tighter the specificity of the profile of performance. However, it is equally possible that something like distractibility impeded ideal performance in real-time on the grammaticality judgement task, whereas something like a verbal memory deficit at the time of acquisition determined the relative strengths of linguistic representations.

The present study has no way of untangling these possibilities, nor of clarifying whether the LA group's imperfect performance was entirely due to task demands, or to youthful and thus still vulnerable linguistic representations, or to some combination of the two. What is apparent is that the children with SLI had disproportionate difficulty with the past tense *-ed* inflection, which could not be alleviated by measures designed to neutralise a speed of processing deficit, suggesting that the proximal cause of their difficulty with this inflection was not a contemporary speed of processing deficit. A viable alternative, not demonstrated by the current results but consistent with them, is that mental representation of the past tense inflection in this group of children with SLI was underdeveloped, due to a cognitive processing deficit active at an earlier stage of language acquisition.

Chapter 8: General Discussion

The experiments reported in this thesis examined the claim that the profile of language difficulties encountered by many children with SLI is at least in part attributable to a deficit in processing spoken language, rather than to absent or abnormal linguistic representations.

Overview of studies

The first three studies were based in the magnocellular hypothesis for developmental dyslexia, which posits that inefficiency in the neural systems responsible for the perception of the dynamic aspects of stimuli, across sensory modalities, is the proximal cause of the literacy problems experienced by individuals with dyslexia. I hypothesised that developmental dyslexia and SLI lie on a continuum of language disorder, differing primarily in severity rather than type. There is a remarkable overlap in incidence between the two disorders, as well as an implicit assumption in much of the research literature that findings in one disorder can be directly applied to the other. Both populations are characterised by phonological deficits, and a large body of research has suggested that these phonological deficits are secondary to a fundamental sensory disorder, which is related to the perception of the brief and rapidly changing sounds necessary for accurate speech perception.

If SLI and developmental dyslexia are underpinned by the same faulty sensory mechanisms, tasks tapping these mechanisms which have revealed deficits in dyslexia should also reveal deficits in SLI. Further, it is uncontroversial that SLI is the broader and more severe disorder of the two, and one could therefore legitimately expect to find more widespread and potentially more striking deficits.

In the first study, I tested the predictions of the magnocellular hypothesis in SLI in the visual domain. Random Dot Kinematograms (RDK) are a well-established psychophysical means of assessing sensitivity to global coherent motion. The detection of coherent motion is subserved by the magnocellular visual pathway, and a number of studies have shown that individuals identified as dyslexic require an unusually high proportion of dots moving in the same direction to be able to detect the direction of motion. Contrary to my experimental predictions, the children with SLI who participated in my study had coherent motion detection thresholds which were indistinguishable from those of chronological-age matched controls. They could not be said to have any deficit in the functioning of their visual magnocellular pathways, at least as far as could be assessed by the use of an RDK. As expected, a control task which used a static form coherence task did not show any group differences; however, unlike the RDK, it did not prove to be a particularly reliable measure.

In the second study, I moved from the visual to the auditory domain: the causal pathway by which a magnocellular deficit is hypothesised to lead to language disorder is via impaired speech perception. It therefore seemed more appropriate to test the perception of auditory rather than visual stimuli in a language disordered population. The detection of frequency modulation (FM) in sound is known to be important in speech perception, and has been shown to be impoverished in developmental dyslexia. I examined sensitivity (in the same children as Study 1) to two rates of FM: 2 Hz, at which the listener must actively track the temporal changes in the stimulus, and 240 Hz, at which rate the changes are too fast for human temporal resolution and are instead analysed using spectral mechanisms. I found partial support for the experimental predictions that children with SLI would have higher FM detection thresholds than age-matched controls at 2 Hz but not 240 Hz FM, and further that these thresholds would correlate with performance on tests of phonological sensitivity (nonword reading and phonological discrimination).

Although there were trends in the predicted directions, these were not significant. It is possible that this was a matter of statistical power, since approximately half the data had to be eliminated because the psychophysical functions obtained were uninterpretable. This was almost certainly due to the demands of a task which, while appropriate for cooperative adults, proved insufficiently motivating for children.

In the third study I used a more child-friendly task format (the 'Dinosaur Game') to obtain FM detection thresholds, in order to ascertain whether the trends present in Study 2 could be confirmed on the basis of a larger pool of data. In addition to 2 Hz and 240 Hz FM, I also obtained detection thresholds for 20 Hz FM, as this rate of change approximates the time-frame of phonemes. Contrary to experimental prediction, no significant group differences emerged for any of the rates of FM tested. Nor did FM sensitivity correlate significantly with either nonword reading or phonological discrimination scores. It would appear, on the basis of this sample of children, that the insensitivity to slow rates of FM reported in developmental dyslexia cannot be generalised to SLI.

In the fourth study, rather than looking for a non-speech auditory deficit that may underlie a phonological deficit in SLI, I decided to examine the phonological deficit itself and its possible relationship to a deficit in inflectional morphology. The experimental predictions, based on performance on a grammaticality judgment task, were twofold. Firstly, that sensitivity to a missing obligatory past tense inflection would depend on the perceptual salience of the specific allomorph, such that there would be fewest errors involving the syllabic /«d/ allomorph, and most errors involving the unvoiced /t/ allomorph, with the voiced /d/ allomorph at an intermediate level. Secondly, that performance on the grammaticality judgement task would correlate with nonword reading and phonological discrimination scores. I found no effect of past tense allomorph, but did find a very robust correlation between grammaticality judgment and nonword reading and phonological discrimination scores, which remained significant even when age and vocabulary level were controlled for.

Using the grammaticality judgement task developed in Study 4, in the final two studies I shifted my perspective away from the idea of a perceptual processing deficit and towards the idea of a higher-level, cognitive processing deficit. In the fifth study I hypothesised that introducing a cognitive stressor, such as increased speech-rate or memory load, would cause young children with typically developing language to make the same types of mistakes usually observed in children with SLI. Specifically, the experimental prediction was that compressing speech-rate by 50%, or doubling the length of a sentence by adding redundant verbiage, would cause children to make most errors with the regular past tense and 3rd person singular inflections, and fewest with the regular plural inflection. A control condition involving prepositions was expected to elicit ceiling performance. With the exception of the control condition these predictions were strongly supported by the data. Increased sentence speed, and to a slightly lesser degree increased sentence length, induced an 'SLI-like' profile of error.

Finally, in the sixth study I attempted to reverse the effects of the putative cognitive stressor in a group of children with SLI, by expanding sentences by 30% and introducing a 500 ms pause following the target word. Neither manipulation had any observable impact on performance on the grammaticality judgement task. However, unlike children in either the chronological-age or the language-age matched control groups, children with SLI consistently performed more poorly on the control prepositions condition than on the regular past tense condition.

The results obtained in this set of studies are consistent with the following conclusions: that the phonological deficits frequently reported in SLI are not attributable to an underlying deficit in tracking dynamic frequency changes in sound; that the difficulties with inflectional morphology consistently found in SLI are not simply attributable to the perceptual salience of the inflections in question, but that there is nonetheless a potentially causal relationship between phonological and morphosyntactic sensitivity; that heavy cognitive processing demands can lead to an SLI-like profile of difficulty with inflectional morphemes in children with intact linguistic representations, and that it is not therefore unreasonable to suggest that a similar mechanism may underlie real cases of SLI; but that alleviation of this putative processing stressor does not remove the difficulty with finite verb-phrase morphology exhibited by English-speaking school-age children with SLI.

Methodological limitations

There are a number of methodological limitations in the studies presented in this thesis, which must be acknowledged. The same group of children participated in Studies 1 through 4, and in none of these studies were they screened for visual or auditory acuity. Poor visual acuity may have impacted on coherent motion detection, but was unlikely to affect the FM detection or grammaticality judgment results. Detection of FM or of inflectional endings, on the other hand, could potentially be affected by poor hearing. However, as far as FM is concerned, this would have been more problematic if positive rather than null results had been obtained. In the case of inflectional morphemes, it also seems unlikely that the results could be explained by hearing loss, particularly in light of the report by Norbury, Bishop and Briscoe (2001) that children with known sensorineural hearing loss were unimpaired on tests of inflectional morphology. Finally, it is important to note that despite the absence of explicit screening at the time of testing, according to parental report none of the participating children had suffered permanent hearing loss; furthermore, children in Language Resource Bases are routinely screened for hearing impairment.

A possible confound in Study 4, which was discussed in the experimental chapter, should be briefly mentioned. The experimental predictions were based on the hypothesis that the high perceptual salience of the syllabic /◀◀d/ allomorph of the regular past tense would make it more obvious when it was absent from an obligatory context than the non-syllabic /d/ and /t/, and therefore that its absence would be detected more often. However, the /◀◀d/ allomorph only appears on verbs whose stem ends in an alveolar stop consonant: stems in the biggest class of no-change irregular verbs also end in alveolar stops and as these tend to be high-frequency words (e.g. *put*, *hit*), it would be quite reasonable for children to conclude that any verb ending in /d/ or /t/ could be considered correctly inflected for the past tense. Thus any effects of perceptual salience of the /◀◀d/ may well have been cancelled out by the frequency effects of this class of no-change verbs. One way round this difficulty would be to examine the 3rd person singular inflection rather than the past tense. In this case, there are also three allomorphs which parallel the past tense allomorphs in their degree of perceptual salience: syllabic /◀◀s/, voiced /z/, and unvoiced /s/. The syllabic /◀◀s/ is used only when the stem ends in /s/ or /▶ /, but here there is no equivalent class of verbs which could be left uninflected for 3rd person singular.

There is a question regarding obligatoriness relevant to all three grammaticality judgement tasks reported here. In a phrase such as *'The boy play in the garden'*, there is no indication as to whether *play* should be inflected for past tense or 3rd person singular. In Study 4, therefore, children's performance could have reflected difficulty with either past tense or 3rd person singular. The fact that all the well-formed sentences were set in the past tense may have given children a clue, but there was nothing in the ill-formed sentences themselves to clarify this ambiguity. In a sense, it is not so important whether children knew which inflection was missing, as long as they noticed that some inflection was missing. However, I thought it appropriate to remove this source of ambiguity in subsequent grammaticality judgement tasks, particularly as in Study 5 I wanted to compare sensitivity to past tense and 3rd person singular inflections. In Studies 5 and 6 tense and number were explicitly marked in all sentences, as in '*Yesterday, the boy play in the garden*' or '*Every day, Mary walk along the river*'. Although removing uncertainty about the appropriate inflection, this introduced a new possible confound: Rice and Oetting (1993) reported that young children with SLI were less likely to produce an obligatory plural *-s* inflection if plurality had already been marked by a number word in the phrase, presumably because they regarded the now-redundant information as unnecessary. This reluctance for double-marking may have had the effect of exaggerating the grammaticality judgement error rate in Studies 5 and 6. In combination with the 2-year age difference between the groups, it may also go towards explaining why the error rate was noticeably higher in the baseline condition of Study 6 than in Study 4, despite otherwise identical tasks.

All three grammaticality judgement tasks used a set of sentences in which the target morphemes were prepositions, as a control condition. The reasoning behind this choice was that prepositions, specifically *in*, *on* and *at*, are relatively short and unstressed function morphemes, and in this respect are comparable to the inflections used in the experimental conditions. They are also acquired early in typical language development, and are not reported as particularly problematic in SLI; as the aim of a control condition is to demonstrate that errors are due to specific difficulty with the experimental variable being tested, and not with the task per se, function morphemes which were likely to elicit ceiling performance seemed a good choice.

In Study 4, prepositions proved to be a successful control condition, eliciting virtually error-free performance from both SLI and control groups. In Study 5, the error rate on prepositions sentences was comparable to that on 3rd person singular sentences, that is, high. In Study 6, the picture was a little more complex: the control groups had similar accuracy on past tense and prepositions sentences, with the older children (chronological-age match) at absolute ceiling, and the younger children (language-age match) at what was interpreted as a relative ceiling imposed by task demands. The children with SLI obtained lower scores on both prepositions and past tense sentences than the younger controls, but within the group, prepositions were significantly better than past tense; the level of performance for prepositions was again tentatively interpreted in terms of a relative ceiling set by task demands.

None of the three prepositions used stood out as consistently problematic across studies, so the question remains as to why they failed to reliably produce error-free performance in the latter two studies. Given their well-established early age of acquisition, it seems unlikely that these were hitherto unrecorded 'problem morphemes'. It is more likely that they demanded a shift in strategy, from focusing on bound morphemes and word-endings, to free-standing morphemes which were necessarily later in the sentence than the target words in all the other sentences. In Study 5, the errors were produced in unusually stressful circumstances, and it is probable that this high level of cognitive stress made it more difficult to switch strategies quickly and effectively. But in Study 6, performance on any of the sentence conditions did not differ from the baseline (normal speech-rate, no pause), which could not be described as unusually stressful, and which was identical to the task in

Study 4. The obvious difference between Study 4, and Studies 5 and 6, was the age of the participants. The mean age in Study 4 was ten, in Study 5 six, and in Study 6 eight for the SLI group and chronological-age control group and five for the language-age control group. If a rough estimate of the language lag in a group of children with SLI is two to three years, the language-ages for the studies could be reinterpreted as Study 4: seven/eight; Study 5: six; Study 6: five. The groups which had difficulty with the prepositions sentences had a language-age (vocabulary level) of six or below, while those who had no difficulty with them had a language-age of seven or above. Perhaps the kind of strategy or attention shifting required for good performance on the prepositions task, at least in the language arena, comes into play once a critical mass of vocabulary (appropriate to a typically developing seven-year old) has built up. One way to avoid the confound of this putative strategy shifting would be to use a bound inflection which is not reported as problematic in SLI: one obvious candidate here is the progressive *-ing* (see Leonard, 1998, for review of *-ing* usage). Another candidate is the noun plural *-s*, which was in fact used in Study 5, and which elicited the good performance required of an effective control condition. In future studies using a similar task, I would choose to use one or both of these inflections as a control in preference to prepositions.

Studies 5 and 6 used speech compression and expansion as manipulations to magnify or relieve the speed-of-information-processing load. However, it should be borne in mind that changes in speech-rate can result in distortions of the speech-signal which may confound the effects of speed with other effects of disproportionately altered phonemes. The algorithms which were used to edit the speech-signal were proprietary algorithms from SoundEdit, who were unwilling to provide detailed information on the action of their compression/expansion function.

An issue which applies to the use of explicit grammaticality judgement tasks, as in Studies 4-6, is that it necessarily involves heavy metalinguistic demands. Conscious reflection on the structure of language is a difficult and late-developing skill, and in general people are far better able to use complex grammars than to comment on them. On the one hand, children with SLI who have been receiving intervention may be more aware of language structure because there is an explicit focus on it in many intervention programs. On the other hand, such metalinguistic knowledge may be particularly tenuous if there is not a solid substrate of primary linguistic knowledge to support it. Children who make few errors on a grammaticality judgement task clearly have both a good grasp of the grammatical structures being tested and the metalinguistic know-how to deal with the task demands. Poor scores, however, could be caused by difficulties with either of these factors.

One way round this problem would be to use an on-line measure such as reaction time on a word-monitoring task, as used by Stark and Montgomery (1995) and Montgomery (2000). A step in this direction was the use of a reaction time measure in Study 6, where it could potentially have illustrated group differences in decision making time. However, the decision making still pertained to an explicit grammaticality judgement, which still involved metalinguistic knowledge. A word-monitoring task by contrast, indirectly taps implicit grammatical knowledge by seeing what effect on reaction time, if any, the (un)grammaticality of the sentence has on the relatively undemanding task of monitoring the sentence for a familiar word.

A final but important methodological issue pertains to the choice of an appropriate control group. In Studies 1-4, the control group was matched to the SLI group in terms of chronological age and nonverbal ability, as assessed by Raven's matrices. In terms of nonverbal maturity, these two groups could be considered equal, and if the language impairment is viewed in terms of language difficulties which are disproportionate to age and nonverbal ability, this control group is sufficient. However, one of the important questions in SLI is whether the language profile is deviant or simply delayed; for answering this question, a language-age control group is necessary. If a particular linguistic structure - such as the past tense inflection - is more problematic for a group of children with SLI than a group of typically developing children of the same language level, it suggests that the language profile is deviant. Although using language age matched controls is a popular strategy, it is not a fool-proof method. Firstly, language is a multi-dimensional skill, and there is no gold standard dictating which aspect of language, and which specific test score, should be used to match groups. Secondly, there is an inherent age confound, so that the disordered group will be older both in terms of chronological and mental age; this may result in the two groups using different strategies to approach the task at hand. Thirdly, while finding group differences in favour of the younger controls does suggest that the children with SLI have disproportionate difficulty with the structure being tested, the converse is not true: that is, a failure to find group differences does not justify the conclusion that the groups are the same, and that language-level can fully account for the language deficit in question (Plante, Swisher, Kiernan & Restrepo, 1993).

Study 6 was the only study in this thesis which included a language age matched control group as well as a chronological age matched group. In this case the comparison was informative, as it illustrated that even when performance was depressed below absolute ceiling, the SLI group had disproportionate difficulty with the past tense inflection as compared to the prepositions. A similar comparison may have been useful in Study 4, in which there were differences between the SLI and chronological age matched groups, which may or may not have remained with a language age matched group. However, in Studies 1-3 there were no group differences; since the children with SLI were no worse than their age matched peers on FM and coherent motion detection, it seems unlikely that a younger control group would have contributed any useful information.

The PLI group

A small group of children identified as Pragmatically Language Impaired (PLI) participated in Studies 1-4. These four children met the inclusionary criteria outlined for children with SLI, but in addition scored below the cut-off score of 132 on the Children's Communication Checklist (Bishop, 1998). The group was too small to merit statistical analysis, but observation of the data suggested that while on the language tasks (including grammaticality judgement) their performance was indistinguishable from that of children with typical SLI, their psychophysical thresholds tended to be higher. This was apparent for the group as a whole on 2 Hz FM detection, but not 20 Hz or 240 Hz. In the coherent motion task, the single dramatically outlying threshold came from a child in the PLI group, who had a typical score on the coherent form task, and whose scores on 2 Hz (but not 240 Hz) FM were also at the upper end of the range. However, there was nothing in terms of age, Raven's matrices or any of the language tests that distinguished him from the rest of the PLI group, which in turn was very similar to the typical SLI group in everything but the CCC scores. The unusually high coherent motion score brings to mind not only the obvious parallel with findings in dyslexia, but also the recent reports of poor coherent motion detection in children diagnosed with autism (Spencer et al., 2000; Milne et al., 2002).

There is increasing interest in the potential region of overlap between language impairments and autism, and the concept of a pragmatic language impairment has been put forward as a tentative link between the two disorders (Bishop & Norbury, 2002). The triad of impairments which characterises autism is usually defined in terms of stereotyped behaviour, and deficits in communication and social understanding. Children with PLI have difficulty with the pragmatics and social use of language. Is it therefore possible that there is any connection between sensitivity to coherent motion and the pragmatics of language use?

There is a substantial literature supporting the idea that children with autism are particularly good at analysing the fine detail of visual stimuli, at the cost of processing global features (the weak central coherence hypothesis; Frith, 1989). For example, Shah and Frith (1983) found that children with autism were better than controls at detecting a target figure embedded in a context of distracting information. It has been suggested that this mode of analysis may underlie their stereotyped behaviour patterns. One could argue that a holistic view is also important for understanding and participating in discourse: a conversation must be viewed as a whole, and focusing on individual statements or words can often be misleading. Similarly the use of metaphors or colloquialisms depends on dissociation from the literal meaning of specific words and a focus instead on the meaning of the whole phrase. Perhaps the same mechanisms are at play for a holistic view of language and a holistic view of an RDK stimulus. There are several necessary leaps of the imagination for this link to be made, not least between the cognitive domains and levels in question. Nevertheless, it is conceivable that an attentional focus on detail over global features could act in a top-down manner to influence not only the analysis of language but also of coherent motion, and that this may speak to the link between PLI and autism.

However, even in the tiny of sample of children identified with PLI for this thesis, the high coherent motion threshold was a single striking exception. More consistent was the tendency towards higher thresholds specifically on 2 Hz FM detection, which is what had been predicted for the typical SLI group. Though coherent motion and FM detection share magnocellular-type function because they require sensitivity to the dynamic aspects of stimuli, they do not really share a requirement for 'global' processing. If anything, slow rate FM detection requires the analysis of detail within the stimulus, so that someone with strengths in analytical over holistic information processing might be predicted to be more rather than less sensitive to FM. That the PLI group as a whole tended to have poor sensitivity to slow rate FM does not support the notion that, at least in the auditory domain, an overlap with autism is due to shared weak central coherence. Given the small sample of children with PLI who participated in Studies 1-4, it is clear that the findings which suggest slightly unusual magnocellular-type function, cannot be given too much weight. Nonetheless, it is an intriguing possibility to consider, particularly in light of a recent study carried out in The Netherlands, which reported an association between tests of auditory attention and scores on the CCC (van Daal, 2002). It would be interesting to see whether perceptual deficits could be demonstrated in a larger sample of children identified as PLI.

Implications for the existence and nature of a processing limitation

The ongoing controversy about how best to explain the causes of SLI can be described in terms of the traditional dichotomy between linguistic competence and performance. Linguistic competence accounts share some basic assumptions about the nature of language in the human mind, namely that it is modular and governed by the rules of Universal Grammar, which is itself innate and genetically transmitted and which unfolds via a maturational mechanism. Modularity, according to Fodor's (1983) characterisation, refers to a system which is, among other things, domain-specific. This allows for highly localised breakdown, so that according to this view it is indeed possible to have a deficit, developmental or acquired, which is limited to language.

Further, the idea of an innate Universal Grammar implies a direct and static mapping between the rules of language in the world and the rules of language in the mind. It is therefore legitimate, according to this view, to describe a mental representation of a linguistic structure in the same terms used to describe the linguistic structure itself. Applying this thinking to SLI, the proximal cause is described as a specifically linguistic - that is, grammatical - representational deficit.

The opposing viewpoint puts forward a processing deficit as the proximal cause of SLI. Processing deficit accounts emphasise the primary role of dynamic aspects of language usage and acquisition, over the representations themselves. However, there are many different flavours of processing accounts, and they differ on at least two dimensions: domain level and specificity. Processing accounts of SLI can be divided according to whether the putative deficit lies at a perceptual or a cognitive level of processing. The auditory deficit hypothesis, with all its variations in terms of the importance of sound brevity or transience, clearly belongs to the former category. By contrast, accounts such as the generalised slowing hypothesis, or hypotheses centred on verbal memory deficits, refer to higher levels of cognition.

On the dimension of domain specificity, processing accounts differ according to whether the proposed deficit is restricted to the realm of language, or whether it is a domain-general deficit which has particularly noticeable impact on language. Once again, the auditory deficit hypothesis places itself firmly in the non language-specific camp. The idea here is that there is a deficit in processing any sound which is brief or presented in rapid sequence or is rapidly changing (depending on the specific account), whether it is found in the speech signal or not, but that the deficit will have disproportionate impact on language because these are exactly the types of sounds that language is built from. The emphasis is on auditory perception, and as such cannot be said to be truly domain-general, although some incarnations of this type of account (e.g. the magnocellular hypothesis) posit a pan-sensory deficit. Sharing the non language-specific outlook is the generalised slowing account, which as its name implies, posits a degree of cognitive slowing in SLI which can be seen in both verbal and nonverbal tasks. Contrasting with this outlook is the position that the problem is contained within the verbal domain: this position is maintained by accounts supporting phonological deficits and their effects as the primary area of concern, such as the mapping hypothesis (Chiat, 2001) or the phonological working memory hypothesis (Gathercole & Baddeley, 1990).

The first set of studies reported in this thesis addressed the issue of a low-level perceptual, non language-specific processing impairment in SLI. The failure to find an FM deficit in children with SLI, as well as the lack of a correlation between slow-rate FM sensitivity and phonological discrimination and nonword reading, suggests that limited ability to track dynamic changes in the acoustic stimulus is not what underlies the poor speech perception and phonological skill associated with SLI. These results are not concordant with an auditory deficit account of SLI. However, they do leave open the possibility of a different low-level, non speech-specific auditory deficit. In various formulations of their hypothesis, Tallal and colleagues postulated that formant transitions would be especially hard-hit by a 'temporal processing deficit'. Formant transitions are characterised by their brevity, but also by a continuous sweep across a range of frequencies which identifies a specific phoneme. FM perception could well be the mechanism responsible for analysis of this particular type of acoustic information, and the finding that it is not impaired in SLI is in line with previous research suggesting that the dynamic element of formant transitions is not a primary obstacle to speech perception in SLI (Sussman, 1993, Tallal & Piercy, 1975). Phoneme brevity, particularly relative to adjacent phonemes, appears to be a more damaging factor (Leonard, 1998) and the type of non-speech auditory deficit which would most closely correspond to this would be more akin to increased backward masking, for which there is evidence in SLI (Wright, 1997; cf. Bishop et al., 1999).

The emphasis on phonological processes in Study 4, and in part in Studies 5 and 6, addresses the possibility of a deficit at a higher level than purely sensory processing, and one which is restricted to the verbal domain. The attempt to demonstrate that sensitivity to a missing obligatory inflection would depend on the perceptual salience of a specific allomorph was confounded by the possibility of frequency effects supporting a no-change strategy for verb stems ending in an alveolar stop. It is also possible that accuracy data alone on an explicit grammaticality judgment task would not be sensitive enough to capture potentially subtle effects of allomorph salience. Nonetheless, the data available was not consistent with the idea that perceptual salience alone could account for sensitivity to a morphological inflection.

However, the repeated finding that phonological discrimination correlates significantly with grammaticality judgment scores, is entirely consistent with a role for phonological sensitivity in the analysis of grammatical inflection. This correlation remained at a level of approximately .4 even when the effects of age and vocabulary level were partialled out, for the SLI groups in both Studies 4 and 6. Even more strikingly it was at a level of .7 for the younger language-matched control group in Study 6. This observation suggests an association between phonological discrimination ability and the sensitivity to grammatical inflections employing these phonological contrasts, which is part of a normal development and which is present in attenuated form in SLI. The lack of a similar correlation in chronologically age matched children* implies a maturational aspect to any language acquisition mechanism which utilises this association: possibly its usefulness is limited and it ceases to play a role once a given level of language proficiency (or vocabulary size) is attained. The results from Study 5 should also be considered, where the same correlation was significant but considerably weaker, at a level between .2 and .3. These children were of a similar age to the language age control group in Study 6, but it should be noted that although both sets of children were within the normal range on both nonverbal and verbal tests (Raven's matrices and BPVS), the Study 5 children tended to have higher scores in both tests, and were relatively advanced for their age. Conceivably, this group of children was already 'growing out of' the hypothetical mechanism.

What could such a mechanism be? One aspect of the role of phonology in language acquisition pertains to phonological memory and its contribution to vocabulary development (Gathercole et al., 1992). Phonological memory is typically assessed using a nonword repetition task, although as pointed out by Snowling, Chiat

---

* Note however that the lack of a phonological discrimination/grammaticality judgement correlation in the chronological age match control groups may be due to ceiling effects; it is possible that tests more sensitive to this range of performance would reveal a similar correlation.

and Hulme (1991), good performance on this task demands at the very least accurate phoneme segmentation and articulatory planning. However, whatever the additional demands, phonological memory is necessary if not sufficient for successful nonword repetition. Studies 4 and 6 included a measure of nonword repetition, but this measure did not have the dramatic and reliable relationship with grammaticality judgment that was observed for the phonological discrimination task. The most straightforward explanation is that the ability to perceive (and report on) differences in phonemes and sequences of phonemes is the same whether these constitute a grammatically loaded inflection or part of a simple lexical item. Effectively this strips inflectional morphemes of their grammatical identity, and taken to the extreme is an unrealistic conclusion. Nonetheless, even a milder version of this idea does not sit at all comfortably with a linguistic account of SLI, in which grammatical identity is all-important and independent of other aspects of language.

The position that a speech-perception deficit may lead to impaired learning or processing of grammatical inflections is very similar to the position taken by auditory deficit accounts, starting one step up-stream. That is, a relatively low-level perceptual impairment is posited, but one that is specific to speech stimuli. This idea is compatible with the surface hypothesis (Leonard, 1998), which suggests that phonemes with low salience will not be fully processed on-line, and also with the mapping hypothesis (Chiat, 2001), which suggests that the mapping process involved in early word learning could be disrupted by such a phonological deficit.

The assumption so far is of bottom-up influences in which speech perception determines the course of grammatical development. However, it is also possible that it is the other way round, and that having to listen for and use the fine-grained phonetic information at the end of words because of its grammatical importance hones one's ability to listen for similar distinctions in other contexts, such as a phonological discrimination task. Simple correlations cannot shed any light on the direction of causation, and as simple correlations are all the results of Studies 4-6 have to offer, I will have to sit on the fence as far as questions of direction are concerned.

In fact, an association does not even necessarily imply a causal relationship, although it is certainly compatible with one. In a study comparing the phonological, language and literacy skills of children with mild-to-moderate hearing impairment and those of children with SLI, Briscoe, Bishop and Norbury (2001) concluded that "major problems in nonword repetition and phonological impairment occurred without clinically significant deficits in wider language and literacy abilities in children with mild-to-moderate sensorineural hearing loss" (p. 329). In this case, although phonological impairment and wider language difficulties co-occurred in the children with SLI, such co-occurrence is clearly not inevitable. This finding is damaging to the hypothesis that phonological skills are of primary importance to wider language development, although two exonerating factors should be kept in mind: firstly, Briscoe et al. report that a subgroup of children with hearing loss who were particularly impaired on phonology tended to have lower scores on the range of language tests, even if performance remained in the normal range. Secondly, it is possible, even likely, that interactions between different levels of language are more important early in development than they are at later stages; the dissociation between phonology and wider language skills found by Briscoe et al. may have been less distinct had the participating children been younger.

A very recent finding which is relevant to this discussion, is based on preliminary data from a large-scale twin study of SLI. Adams and Bishop (2002) report evidence that nonword repetition and production of grammatical inflections marking verb finiteness have independent heritability. In principle, therefore, these two skills need not co-exist and the causal chain may seem to be again imperilled. However, independent heritability does not mean that when the two factors do co-exist, they will not influence each other. Taken from Rethinking Innateness (Elman et al., 1996) the following example from the neural development of the chicken is surprisingly relevant. Two independent brain systems influence chick imprinting behaviour: *Conspec* refers to an attentional bias to focus on the head and neck region of hen-like objects, while a specific region in the forebrain subserves a learning system called the Intermediate and Medial Hyperstriatum Ventrale (IMHV). Although there is no internal connection between the two systems and they are subserved by different brain regions (and may well be coded for by different genes), their interaction is crucial to normal chick imprinting: by directing the chick's experience in its environment, *Conspec* effectively selects the input for IMHV, and thus determines which representations will be formed in the imprinting process. In a similar way, the interaction between phonological and grammatical skills in language development may well be independent of whether they are underpinned by the same genes or not.

Studies 5 and 6 took a somewhat different perspective on the idea of a processing deficit as a causal factor in SLI, and examined the extent - if any - to which explicitly manipulating a putative stress factor can affect the language profile. This approach, and in particular the simulation experiment in Study 5, has the advantage of being able to test the plausibility of a range of possible processing impairments, rather than being wedded to a single one; in this sense it is better able to disprove a representational deficit than to prove a particular processing deficit. In this case, the finding that verb-phrase morphology can be selectively damaged by introducing unusual cognitive stress, demonstrates that it is possible to have the language profile associated with SLI in the face of intact linguistic representations. But it doesn't demonstrate the presence of this putative cognitive stress in children with SLI, let alone its causal influence; this would have been done had Study 6 been successful in improving children's performance as a result of the sentence manipulations, but it was not.

The inspiration for the simulation study was drawn from the recent work of Bates and colleagues (Blackwell & Bates, 1995; Dick et al., 2001) who, based on simulations with unimpaired adults, argued that performance rather than competence factors can account for the linguistic profile associated with Broca's aphasia. There are a couple of important issues which arise when applying this paradigm to the exploration of SLI; the first relates to the direct transfer of a methodology from adult acquired disorders to developmental disorders in children, while the second relates to the interpretation of a factor used in a simulation in terms of a deficit in the actual disorder.

The emphasis on the grammatical difficulties experienced by children with SLI has sometimes led to the use of the term 'agrammatism'. This immediately implies a parallel with traditional definitions of Broca's aphasia, in which the lack of fluency and grammatical difficulties disproportionate to the lexical level originally resulted in the 'agrammatism' label. Some investigators (e.g. Snow & Swisher, 1996) have gone so far as to suggest that a direct analogy should be drawn between the two disorders and state that "our approach is then to infer, by analogical reasoning, the neuroanatomical basis of... SLI from what is known about the neuroanatomical basis of...aphasia" (p. 453). Although it's possible that such an approach may provide some useful pointers, Bishop (1997) argues forcefully against directly applying to children a model of cognitive processing derived from adults.

Adults have fully formed language systems, and it is conceivable that damage to one part of the system may have reasonably localised effects. Children, on the other hand, are undergoing development, with all the fluidity of mental processing that implies: representations are being formed and changed over time, and it is probable that there is a far greater degree of interaction between levels of processing in children than there is in adults. Disrupting part of this dynamic system will almost certainly have diffuse effects which are difficult to isolate: some processes or representations may be spared, some may never develop, while others may develop in deviant ways as a result of compensatory mechanisms.

If one assumes that a processing deficit in SLI is likely to have been present in infancy and early childhood, then it seems almost inevitable that it would impact on early language learning and the course of linguistic development, including the establishment of representations. On this view it is unsurprising that Study 6 was unable to show significant improvement on past tense *-ed* sensitivity, since an early deficit may well have interfered with the appropriate representation of the inflection. Note that this position does not sit well with a stronger form of a performance deficit account, such as Bishop's (1994) suggestion of a vulnerable markers hypothesis, in which grammatical structures are regarded as reasonably intact, with the difficulty lying in "children's ability to deploy these structure resources under the real-time demands of conversation" (Fletcher, 1992, p. 155). The emphasis here is on production of inflections, which draws more heavily on processing capacity than in the case of receptive language. Nonetheless, my current suggestion based on the results of Studies 5 and 6, is that the representation of inflections is not intact in SLI, but that the reason it is not intact is an early processing deficit rather than the faulty unfolding of an innate Universal Grammar.

The obvious question then remains: what is the processing deficit? The stress factors used in the studies of Bates and colleagues were classified in terms of 'peripheral' and 'central' interference, which correspond to the perceptual versus cognitive processing impairments discussed earlier with reference to SLI. 'Central' stress factors included dual task paradigms, such as a digit recall task presented simultaneously with a sentence comprehension task. 'Peripheral' factors included sentence compression and low-pass filtering, both of which were found to be highly effective stressors (and more consistently so than digit recall).

This raises an interesting question about how best to describe the sentence compression manipulation used in Study 5. It could be viewed as simulating a 'speed of information processing deficit' of the sort put forward in the generalised slowing hypothesis by Kail and colleagues (Kail, 1994). Kail (2000) suggests a global mechanism which limits processing speed on most tasks, across many domains, which develops with age and which is an integral part of intelligence. Although he speculates on possible biological bases of processing speed, such as efficiency of synaptic firing or neuronal conductivity, Kail's proposed mechanism is clearly domain-general and applicable to higher-level cognition. However, it could equally apply to sensory processes, in which case it becomes a generalised version of the auditory deficit hypothesis. The implication for Studies 5 and 6 is that the manipulation of sentence speed, and its effects on sentence processing and grammaticality judgement, does not reflect a general property of higher level cognition, but a specific speech perception process. Both of the sentence manipulations used in Study 5, sentence speed and length, would then fall under the category of verbal stress factors.

The finding in Study 5 that sentence speeding produces more distinct differentiation between verb-phrase and noun-phrase morphology than sentence lengthening gives speed the edge as a candidate processing deficit in SLI. The same method of simulating an SLI-profile with different stressors could usefully be applied in future studies as a test of plausible candidates for a processing deficit, ideally with a range of different target profiles. However, it is not sufficient for a candidate to be plausible, it must also be shown to exist in cases of real SLI: the difficulty with demonstrating this directly is that if the damage was done early enough, it may be too late to undo it with intervention studies later on.[*] One way around this problem would be to carry out prospective, longitudinal studies, in which measures of the candidate processes can be used to predict language outcomes.

Finally, it is possible that any number of different stress factors can result in a similar outcome. It is apparent from the studies of Bates and colleagues, as well as Study 5, that sentence compression, sentence lengthening, low-pass filtering, and digit recall can all produce an approximation of a specific disordered linguistic profile. In a similar vein, Lum (2002) demonstrated that giving typically developing children sentences which were semantically odd caused them great difficulty with past tense -*ed* and 3rd person singular -*s*, but not with plural -*s* or progressive -*ing*. One begins to suspect that it doesn't matter what the stressor is; that as long as the system is being taxed sufficiently, the same profile will always emerge. Although this is extreme phrasing, the essential idea is an important part of the connectionist outlook embraced

[*] This implies that clinical interventions, particularly for older children, are effective because they institute compensatory mechanisms, rather than because they reverse the underlying deficit.

by the Competition Model, which places great emphasis on the nature of the 'problem space'; in this case, the typology of a given language. By virtue of their salience or usefulness, some language structures will be more robustly represented than others, and so will be less vulnerable to loss when the processing capacity of the system is exceeded. As has been suggested by Bishop (Bishop et al, 1999; Bishop, 2001), it is unlikely that there is a single cause of SLI, which is well-established as a highly heterogeneous disorder. Rather, it seems increasingly probable that there is a mosaic of risk factors which in various permutations, and in combination with the language being acquired, can lead to the collection of language difficulties experienced by many children with specific language impairment.

Key for Appendices I, II, and III

The tables in the following appendices list frequency information for the target words used in the grammaticality judgement tasks reported in chapters 5, 6, and 7. Adult language frequencies for stem and inflected forms are derived from the Kucera and Francis database (Kucera & Francis, 1967). Child language frequencies are derived from the following English-language corpora from the CHILDES database: Bliss, Brown, Carterette & Jones, Cornell, Evans, Fletcher, Garvey, Gathercole, Gleason, Hall, Kuczaj, Sachs, Warren-Leubecker, and Wells.

Appendix I
Sentence Stimuli for Chapter 5

Sentence: Past tense /◀◀d/	**KF Stem**	**KF Inflected**	**CHILDES Stem**	**CHILDES Inflected**
Sentence Set A well-formed; Set B ill-formed				
Mary **cheat*ed*** at all the games	3	4	17	5
Mark **count*ed*** all the apples in the basket	49	17	329	8
Anne **hat*ed*** orange-juice at breakfast	42	28	224	8
Mary **paint*ed*** a picture every day	37	40	377	44
Mary **point*ed*** at the big sign	395	74	151	11
Granny **rest*ed*** every afternoon	163	17	254	1
Mary **squirt*ed*** Anne with some water	1	1	20	3
Anne **toast*ed*** a slice of bread	19	2	172	10
Mark **trust*ed*** all his friends	52	11	6	1
Jane **want*ed*** a Gameboy for Christmas	329	226	12245	538
Sentence Set A ill-formed; Set B well-formed				
Mary **faint*ed*** in school one day	25	1	7	3
John **fold*ed*** all the napkins neatly	7	15	97	21
The man **lift*ed*** all the heavy boxes	23	43	76	2
The ice-cream **melt*ed*** in the sun	4	9	29	17
Granny **mend*ed*** a teddy-bear	2	1	9	5
Mark **plant*ed*** a tree in the garden	125	11	100	13
John **tast*ed*** every pudding at the party	59	10	421	37
The lady **rent*ed*** a big house	21	7	16	5
Mum **roast*ed*** a big piece of meat	10	5	24	5
John **wast*ed*** a lot of time	35	16	29	5

Appendix I

Sentence: Past tense /d/	**KF Stem**	**KF Inflected**	**CHILDES Stem**	**CHILDES Inflected**
Sentence Set A well-formed; Set B ill-formed				
The father **car**_ed_ about his son	162	15	360	1
John **climb**_ed_ up the tree very fast	12	44	152	79
Mother **clos**_ed_ all the windows at night	34	106	465	107
Mary **dri**_ed_ all the dishes	68	28	185	20
Anne **glu**_ed_ a picture into her notebook	8	19	191	23
Mary **hugg**_ed_ all her friends	3	2	24	1
Anne **pour**_ed_ a glass of milk	9	29	209	21
The monster **scar**_ed_ all the children	3	21	35	179
Jane **shar**_ed_ all her toys with her friend	98	40	88	7
Mary **wav**_ed_ at the people on the train	46	16	29	7
Sentence Set A ill-formed; Set B well-formed				
David **clean**_ed_ all the dirty dishes	70	16	383	24
The baby **crawl**_ed_ around the room	11	20	13	9
Anne **cri**_ed_ all the time	48	30	162	42
John **fill**_ed_ a bucket with water	50	99	49	36
The lion **growl**_ed_ at Mark	4	4	6	1
John **phon**_ed_ all his friends last night	54	5	167	1
The boy **pull**_ed_ a leaf off the tree	51	73	430	89
The sailor **ti**_ed_ a very tight knot	23	34	303	71
John **us**_ed_ a key to open the door	589	612	968	438
David **yawn**_ed_ a lot in school	2	0	1	1

Appendix I

Sentence: Past tense /t/	**KF Stem**	**KF Inflected**	**CHILDES Stem**	**CHILDES Inflected**
Sentence Set A well-formed; Set B ill-formed				
David **bump*ed*** a car with his bicycle	5	2	100	41
The girl **clapp*ed*** after the show	1	4	114	4
John **crash*ed*** a bike in the playground	20	12	52	34
John **kick*ed*** a small dog	16	18	155	52
Granny **lik*ed*** all the flowers	1290	58	10698	90
Lucy **miss*ed*** all the fun at the party	258	40	528	176
Mother **shopp*ed*** at the market	63	0	81	0
The driver **stopp*ed*** at the traffic lights	120	129	1389	64
John **thank*ed*** Amy for her help	36	6	1012	0
Lucy **walk*ed*** along the river	100	169	495	75
Sentence Set A ill-formed; Set B well-formed				
Dad **fix*ed*** a dent in his car	14	87	407	106
Lucy **guess*ed*** all the answers in the game	56	15	866	16
Mary **jump*ed*** over the fence	24	35	390	118
John **knock*ed*** on the green door	15	31	239	105
John **mash*ed*** all the potatoes	1	3	35	28
John **push*ed*** a rock across the path	37	53	415	89
Alice **skipp*ed*** across the road	5	8	26	8
Lucy **talk*ed*** about the party	154	58	1178	51
Mary **touch*ed*** a hot plate	87	42	470	44
Mark **watch*ed*** a lot of television	81	81	1594	76

Appendix I

Sentence: Prepositions *in, on, at*	**KF Stem**	**KF Inflected**	**CHILDES Stem**	**CHILDES Inflected**
Sentence Set A well-formed; Set B ill-formed				
Mary **cooked** a sausage ***in*** the pan	47	10	213	64
Anne **kissed** a boy ***in*** her class	17	15	141	25
The aeroplane **landed** ***in*** the airport	217	15	90	26
The boy **played** ***in*** the park	200	104	2903	183
Sarah **called** Amy ***on*** the phone	188	401	754	522
John **dropped** a brick ***on*** his foot	59	101	212	137
Mary **slipped** ***on*** the wet pavement	19	32	46	23
The girl **laughed** ***at*** the jokes	28	51	86	34
Anne **screamed** ***at*** the monster	13	17	39	8
Anne **tried** all the games ***at*** the party	140	170	1207	107
Sentence Set A ill-formed; Set B well-formed				
The dog **chased** a cat ***in*** the garden	18	1	47	10
The family **lived** ***in*** a caravan	177	115	356	50
Mark **saved** all his money ***in*** a piggybank	62	43	163	17
The stick **floated** ***on*** the water	3	7	20	5
Anne **picked** all the roses ***on*** the bush	55	78	751	147
Susan **stayed** ***on*** a farm	113	75	871	58
The baby **smiled** ***at*** everyone	58	71	41	4
Anne **danced** a lot ***at*** the party	90	10	144	9
John **looked** ***at*** the big picture	399	367	6861	187
Mary **waited** ***at*** the bus-stop	94	70	2422	10

Appendix II
Sentence Stimuli for Chapter 6

Sentences: Plural /z/	KF Stem	KF Inflected	CHILDES Stem	CHILDES Inflected
Sentence Sets A, C, E, G well-formed; Sets B, D, F, H ill-formed				
Yesterday, we saw two **birds** in a tall tree				
Yesterday, my little sister saw two **birds** in a big, tall, leafy pretty green tree	31	57	328	106
Every week, all the **boys** at school play football				
Every week, all the big, strong, fast **boys** at my school play lots of football at playtime	242	143	1629	408
Every week, all my **friends** eat lunch together				
Every week, all of my nice, funny **friends** eat a big, yummy lunch together	133	162	663	269
Every day, Mark eats two **eggs** at breakfast				
Every day, Mark and his brother eat two **eggs** and lots of buttered toast at breakfast	12	35	190	146
Last week, we planted two **trees** in our back garden				
Last week, mum and dad and I planted two new **trees** in our big, exciting back garden	59	101	669	91
Sentence Sets A, C, E, G ill-formed; Sets B, D, F, H well-formed				
Yesterday, we saw three **bears** in the forest				
Yesterday, my sister saw three brown **bears** in the big, dark, scary forest	57	26	198	42
Every week, John brings ten **chairs** into the room				
Every week, John and Rebecca bring all the **chairs** into the very dark and empty room	66	23	757	98
Every day, all the **girls** in my class listen to music				
Every day, all of the lovely friendly **girls** in my class listen to loud, beautiful music	220	142	1166	370
Last week, Tom saw six **pigs** in a big muddy field				
Last week, Tom saw six fat, pink, happy **pigs** in an enormous, muddy, smelly field	8	6	280	130
Yesterday, Tom put three **stones** in his coat pockets				
Yesterday, David put three heavy, white **stones** in his big, yellow coat pockets	58	12	23	11

Appendix II

Sentences: Plural /s/

	KF Stem	KF Inflected	CHILDES Stem	CHILDES Inflected
Sentence Sets A, C, E, G well-formed; Sets B, D, F, H ill-formed				
Yesterday, Jane bought two **books** in the bookshop				
Yesterday, Jane and her mum bought some **books** in the big, enormous fun bookshop	193	96	781	171
Every day, both our **cats** eat a tasty dinner				
Every day, both of our cute, cuddly **cats** eat a very big and tasty dinner	23	18	887	169
Every week, Tom sees all the **ducks** in the pond				
Every week, Tom and his brother see some **ducks** in the very big, round, green-and-blue pond	9	4	251	113
Last week, there were five **hats** in the hat-shop				
Last week, there were lots of nice, pretty **hats** in the big, new, exciting hat-shop	56	14	593	48
Yesterday, I put five **plates** on the top shelf				
Yesterday, Jennifer and David put some **plates** in the small, orange, secret cupboard	22	23	335	71
Sentence Sets A, C, E, G ill-formed; Sets B, D, F, H well-formed				
Last week, we sailed two **boats** around the lake				
Last week, my sister and I sailed two **boats** all around the enormous blue lake	72	51	374	41
Every week, there are lots of **coats** on the coat-hooks				
Every week, there are lots of woolly **coats** on the big, yellow, plastic coat-hooks	43	10	449	28
Every day, there are ten **cups** in the yellow cupboard				
Every day, there are at least five or ten **cups** in the big orange and yellow cupboard	45	14	403	114
Every day, John puts five **forks** out on the table				
Every day, John and Jennifer put five clean **forks** out on the new wooden kitchen table	14	7	210	17
Last week, I saw ten **trucks** on the road				
Last week, I saw some very big, red **trucks** on the very wide, long, bumpy road	57	22	498	39

Appendix II

Sentences: 3rd Person Singular /z/

Sentence	KF Stem	KF Inflected	CHILDES Stem	CHILDES Inflected
Sentence Sets A, C, E, G well-formed; Sets B, D, F, H ill-formed				
Every day, Mary **dries** all the wet dishes				
Every day, my big, strong sister Mary **dries** all the pretty blue-and-white dishes	68	1	185	33
Every week, Christopher **folds** all the napkins neatly				
Every week, my tall cousin Christopher **folds** all the purple napkins very neatly	7	3	97	6
Every week, Emily **glues** a picture into her notebook				
Every week, my best friend Emily **glues** a picture into her special blue notebook	8	0	191	1
Every week, Rebecca **phones** all her friends				
Every week, my big sister Rebecca **phones** all her loud, silly, funny friends	54	7	167	17
Every day, David **yawns** a lot in school				
Every day, the sleepy little boy **yawns** a lot in the small, warm, village school	2	0	1	2
Sentence Sets A, C, E, G ill-formed; Sets B, D, F, H well-formed				
Every day, David **cleans** all the dirty dishes				
Every day, the helpful little boy **cleans** all the dirty green-and-white dishes	70	1	383	6
Every day, the baby **crawls** around the room				
Every day, the happy, laughing baby **crawls** around the big, colourful living-room	11	2	13	2
Every day, Sarah **pours** a glass of milk				
Every day, the thirsty little girl **pours** a big glass of cold chocolate milk	9	2	209	5
Every week, Emily **shares** all her toys with her friend				
Every week, my short cousin Emily **shares** all her toys with her tall, pretty friend	98	46	88	0
Every week, Mary **waves** at the people on the train				
Every week, my little sister Mary **waves** at all the people on the noisy, red train	46	51	29	14

Sentences: 3rd Person Singular /s/	KF Stem	KF Inflected	CHILDES Stem	CHILDES Inflected
Sentence Sets A, C, E, G well-formed; Sets B, D, F, H ill-formed				
Every day, Mary **jumps** over the fence at home				
Every day, my tall big sister Mary **jumps** over the high, wooden fence at home	24	2	390	24
Every day, Jonathan **knocks** on the green door				
Every day, my little cousin Jonathan **knocks** on the small, wooden, green-and-white door	15	2	239	8
Every week, the man **lifts** all the heavy boxes				
Every week, the very tall, strong man **lifts** all the huge, heavy black-and-white boxes	23	2	76	0
Every day, Granny **rests** in the afternoon				
Every day, my nice, sweet old Granny **rests** in her warm comfy chair in the afternoon	163	18	254	1
Every week, Rebecca **walks** along the river				
Every week, my best friend Rebecca **walks** along the long, beautiful river	100	13	495	45
Sentence Sets A, C, E, G ill-formed; Sets B, D, F, H well-formed				
Every week, Mary **cheats** at all the games				
Every week, the horrid little girl **cheats** at all the fun, exciting games	3	0	71	1
Every day, David **kicks** a big football				
Every day, my little cousin David **kicks** a big, round, yellow plastic football	16	3	155	6
Every week, Jennifer **paints** a picture at school				
Every week, my little sister Sarah **paints** a pretty, colourful picture at school	37	10	377	22
Every week, Mother **shops** at the supermarket				
Every week, my clever mother **shops** at the new enormous supermarket	63	17	81	10
Every day, the driver **stops** at the traffic lights				
Every day, the careful, sensible driver **stops** at the red traffic lights on the corner	120	8	1389	25

Appendix II

Sentences: Past tense /d/

	KF Stem	KF Inflected	CHILDES Stem	CHILDES Inflected
Sentence Sets A, C, E, G well-formed; Sets B, D, F, H ill-formed				
Last week Jonathan **climb*ed*** up the tree very fast				
Last week, my little brother Jonathan **climb*ed*** up the big, tall, leafy tree very fast	12	44	152	79
Yesterday, the teacher **clos*ed*** all the windows				
Yesterday, the nice, friendly teacher **clos*ed*** all the big, glass doors and windows	234	106	465	107
Last week, the lion **growl*ed*** at David				
Last week, the huge, yellow, angry lion **growl*ed*** at the silly, ugly little boy	4	4	6	1
Yesterday, the sailor **ti*ed*** a very tight knot				
Yesterday, the brave, strong, clever sailor **ti*ed*** a very tight knot with a piece of rope	23	34	303	71
Last week, Jonathan **us*ed*** a key to lock the door				
Last week, Christopher and Rebecca **us*ed*** a big, orange key to lock the door	589	612	968	438
Sentence Sets A, C, E, G ill-formed; Sets B, D, F, H well-formed				
Yesterday, Rebecca **cri*ed*** all afternoon				
Yesterday, my little sister Rebecca **cri*ed*** all afternoon when she hurt herself	48	30	162	42
Last week, Jennifer **fill*ed*** a bucket with water				
Last week, Jonathan and Jennifer **fill*ed*** a big green bucket with lots of water	50	99	49	36
Yesterday, Caroline **hugged** all her friends				
Yesterday, my nice cousin Caroline **hugg*ed*** all her wonderful, funny, kind friends	3	2	24	1
Yesterday, the boy **pull*ed*** a leaf off the tree				
Yesterday, the short, brown-haired boy **pull*ed*** a shiny green leaf off the big tall tree	51	73	430	89
Last week, the monster **scar*ed*** all the children				
Last week, the gigantic, wild, green monster **scar*ed*** all the sleepy little children	3	21	35	179

Appendix II

Sentences: Past tense /t/	KF Stem	KF Inflected	CHILDES Stem	CHILDES Inflected
Sentence Sets A, C, E, G well-formed; Sets B, D, F, H ill-formed				
Yesterday, the dog **chas*ed*** a cat in the garden				
Yesterday, the big, brown, shaggy dog **chas*ed*** a small black-and-white cat in the garden	18	1	47	10
Last week, Emily **clapp*ed*** after the show				
Last week, the happy, smiling little girl **clapp*ed*** after the exciting Christmas show	1	4	114	4
Yesterday, Dorothy **mash*ed*** all the potatoes				
Yesterday, Christopher and Dorothy **mash*ed*** all the potatoes in a big red pot	1	3	35	28
Last week, Jennifer **watch*ed*** a lot of television				
Last week, my silly cousin Jennifer **watch*ed*** a lot of boring television	81	81	1594	76
Yesterday, Rebecca **wrapp*ed*** a present for her mum				
Yesterday, my best friend Rebecca **wrapp*ed*** a pretty birthday present for her mum	5	14	42	18
Sentence Sets A, C, E, G ill-formed; Sets B, D, F, H well-formed				
Last week, Jonathan **crash*ed*** a bike in the playground				
Last week, my silly cousin Jonathan **crash*ed*** a brand-new bike in the school playground	20	12	52	34
Last week, my father **fix*ed*** a dent in his car				
Last week, my very clever father **fix*ed*** a nasty dent in his shiny new car	14	87	407	106
Last week, Lucy **guess*ed*** all the answers in the game				
Last week, my clever friend Jennifer **guess*ed*** all the right answers in the difficult game	56	15	866	16
Yesterday, Rebecca **talk*ed*** about the party				
Yesterday, Rebecca and Jonathan **talk*ed*** about the exciting birthday party	154	58	1178	51
Yesterday, Christopher **touch*ed*** a hot plate				
Yesterday, my little brother David **touch*ed*** a terribly, horribly hot plate	87	42	470	44

Appendix II

Sentences: Prepositions *in, on, at*	**KF Stem**	**KF Inflected**	**CHILDES Stem**	**CHILDES Inflected**
Sentence Sets A, C, E, G well-formed; Sets B, D, F, H ill-formed				
Every week, Tom **cooks** ***in*** the downstairs kitchen		8		16
Every week, David and Sarah **cook** ***in*** the dark, gloomy, cold downstairs kitchen	47	na	213	na
Yesterday, Sue **fainted** ***in*** the school playground				
Yesterday, my big sister Sue **fainted** ***in*** the very loud and noisy school playground	177	115	355	50
Last week, Jane kissed a **boy** ***in*** her class				
Last week, my silly cousin Jane kissed a **boy** *in* her class at the small primary school	242	143	1629	408
Every week, we **play** ***in*** the park near our house				
Every week, my cousins and I **play** ***in*** the huge, exciting park near our house	200	na	2903	na
Last week, Tom dropped a **brick** ***on*** his right foot				
Last week, my brother Tom dropped a **brick** ***on*** his very big, smelly, ugly right foot	18	na	25	na
Every day, I pat my **dog** ***on*** the head				
Every day, I pat my big friendly **dog** ***on*** his beautiful, hairy, shiny brown head	75	na	989	na
Yesterday, I **slipped** ***on*** the wet pavement				
Yesterday, Mary and David **slipped** ***on*** the slippery, shiny wet pavement	19	32	46	23
Yesterday, Jane **screamed** ***at*** the green monster				
Yesterday, my very brave friend Jane **screamed** ***at*** the huge, scary, slimy green monster	13	17	39	8
Every day, the baby **smiles** ***at*** everyone in the room				
Every day, the cute, tiny baby **smiles** ***at*** all the happy, laughing grown-ups in the room	58	11	41	1
Every week, Sue **waits** ***at*** the bus-stop for the bus		2		9
Every week, Christopher and Sue **wait** ***at*** the cold bus-stop for the big red bus	94	na	2422	na

Appendix II

Sentences: Prepositions *in, on, at*

Sentence	KF Stem	KF Inflected	CHILDES Stem	CHILDES Inflected
Sentence Sets A, C, E, G ill-formed; Sets B, D, F, H well-formed				
Every day, the planes **land** ***in*** the big airport				
Every day, the big noisy planes **land** ***in*** the big, ugly, nearby airport	217	na	90	na
Last week, the snow **melted** ***in*** the afternoon sun				
Last week, the pretty white snow **melted** ***in*** the very warm, bright afternoon sun	4	9	29	17
Yesterday, Tom saw **plums** ***in*** the fruit-basket				
Yesterday, Jennifer and Tom saw **plums** ***in*** the big, full, colourful fruit-basket	1	0	2	3
Every day, there are **socks** ***in*** the laundry basket				
Every day, there are lots of dirty **socks** ***in*** the big, full, smelly laundry basket	4	1	34	101
Every week, Sarah **calls** Amy ***on*** the phone				
Every week, Sarah **calls** her best friend Amy ***on*** the phone for a very nice, long chat	188	70	756	47
Last week, Tom **stayed** ***on*** a farm that had chickens				
Last week, Rebecca and David **stayed** ***on*** a farm that had lots of clucking chickens	113	75	871	58
Every day, Tom puts **sugar** ***on*** his cornflakes				
Every day, Tom puts lots and lots of **sugar** ***on*** his yummy, crunchy, yellow cornflakes	34	na	254	na
Yesterday, Sue **danced** ***at*** the birthday-party				
Yesterday, Susan and Jennifer **danced** ***at*** the wonderful, exciting birthday-party	90	10	144	9
Last week, we **laughed** ***at*** all the jokes				
Last week, mummy and daddy **laughed** ***at*** all the very funny jokes and stories	28	51	86	34
Every week, I **look** ***at*** some beautiful pictures				
Every week, my best friend and I **look** ***at*** some beautiful pictures in the museum	399	367	6861	187

Appendix III
Sentence Stimuli for Chapter 7

Sentences: Past tense -*d*	**KF Stem**	**KF Inflected**	**CHILDES Stem**	**CHILDES Inflected**
Sentence Set A well-formed, Set B ill-formed				
Yesterday, Mary **dri*ed*** all the wet dishes	68	28	185	20
Last week, Rebecca **phon*ed*** all her friends	54	5	167	1
Yesterday, David **clean*ed*** all the dirty plates	70	16	383	24
Last week, Emily **stay*ed*** on a farm that had cows	113	75	871	58
Yesterday, Jennifer **fill*ed*** a bucket with water	50	99	49	36
Sentence Set A ill-formed, Set B well-formed				
Last week, the baby **crawl*ed*** around the room	11	20	13	9
Last week, Emily **shar*ed*** all her toys with her friend	98	40	88	7
Yesterday, Mary **danc*ed*** at the party	90	10	144	9
Yesterday, Sarah **pour*ed*** a glass of milk	9	29	209	21
Last week, Emily **glu*ed*** a picture into her notebook	8	19	191	23
Sentence Set C well-formed, Set D ill-formed				
Last week Jonathan **climb*ed*** a very tall tree	12	44	152	79
Yesterday, the teacher **clos*ed*** all the windows	34	106	465	107
Last week, the lion **growl*ed*** at David	4	4	6	1
Yesterday, the sailor **ti*ed*** a very tight knot	23	34	303	71
Last week, Jonathan **us*ed*** a key to lock the door	589	612	968	438
Sentence Set C ill-formed, Set D well-formed				
Last week, the monster **scar*ed*** all the little children	3	21	35	179
Yesterday, Rebecca **cri*ed*** all afternoon	48	30	162	42
Last week, Caroline **hugg*ed*** all of her friends	3	2	24	1
Yesterday, the boy **pull*ed*** a leaf off the tree	51	73	430	89
Yesterday, we **play*ed*** in the park near our house	200	104	2903	183

Appendix III

Sentences: Past tense *-t*	KF Stem	KF Inflected	CHILDES Stem	CHILDES Inflected
Sentence Set A well-formed, Set B ill-formed				
Last week, Emily **jump*ed*** over the fence at home	24	35	390	118
Yesterday, Jonathan **knock*ed*** on the green door	15	31	239	105
Last week, Jane **kiss*ed*** a boy in her class	17	15	141	25
Yesterday, Alice **skipp*ed*** across the playground	5	8	26	8
Last week, Rebecca **walk*ed*** along the river	100	169	495	75
Sentence Set A ill-formed, Set B well-formed				
Yesterday, the driver **stopp*ed*** at the traffic lights	120	129	1389	64
Last week, Jonathan **bump*ed*** a car with his bike	5	2	100	41
Yesterday, David **thank*ed*** Amy for her help	36	6	1012	0
Last week, Rebecca **shopp*ed*** at the supermarket	63	0	81	0
Yesterday, David **kick*ed*** a big football	16	18	155	52
Sentence Set C well-formed, Set D ill-formed				
Yesterday, the dog **chas*ed*** a cat in the garden	18	1	47	10
Last week, Emily **clapp*ed*** after the show	1	4	114	4
Yesterday, Dorothy **mash*ed*** all the potatoes	1	3	35	28
Last week, Jennifer **watch*ed*** a lot of TV	81	81	1594	76
Yesterday, Rebecca **wrapp*ed*** a present for her mum	5	14	42	18
Sentence Set C ill-formed, Set D well-formed				
Last week, Jonathan **crash*ed*** a bike in the playground	20	12	52	34
Last week, my father **fix*ed*** a dent in his car	14	87	407	106
Last week, Lucy **guess*ed*** all the answers	56	15	866	16
Yesterday, Rebecca **talk*ed*** about the party	154	58	1178	51
Yesterday, Christopher **touch*ed*** a hot plate	87	42	470	44

Appendix III

Sentences: Prepositions *in, on, at*	**KF Stem**	**KF Inflected**	**CHILDES Stem**	**CHILDES Inflected**
Sentence Set A well-formed, Set B ill-formed				
Yesterday, we saw a **bird** ***in*** a big tall tree	31	na	328	na
Last week, Tom saw **ducks** ***in*** the big round pond	9	4	251	113
Last week, we planted **trees** ***in*** our back garden	59	101	669	91
Yesterday, we **swam** ***in*** the enormous swimming-pool	15	6	135	11
Last week, Tom got five **cards** ***on*** his birthday	26	36	2421	271
Yesterday, I put the **plates** ***on*** the very top shelf	22	23	335	71
Last week, John **sat** ***on*** the big comfy chair	67	150	1658	94
Yesterday, Mark ate **eggs** ***at*** breakfast-time	12	35	190	146
Yesterday, Jane bought **food** ***at*** the vegetable market	147	na	580	na
Last week, we played **games** ***at*** the birthday-party	123	55	818	169
Sentence Set A ill-formed, Set B well-formed				
Yesterday, we saw **bears** ***in*** the big dark forest	57	26	198	42
Yesterday, the **girls** ***in*** my class sang a song	220	142	1166	370
Last week, Tom saw **pigs** ***in*** a big muddy field	8	6	280	130
Yesterday, our cat **sat** ***on*** the warm sunny roof	67	150	1658	94
Last week, there were **coats** ***on*** all of the coat-hooks	43	10	449	28
Yesterday, there were **sweets** ***on*** the big orange plate	70	2	117	34
Last week, I saw some **trucks** ***on*** the big wide road	57	22	498	39
Yesterday, John threw the **ball** ***at*** the big tall boy	110	na	749	na
Last week, the **boys** ***at*** school played lots of football	242	143	1629	408
Last week, I saw a **play** ***at*** the new theatre	200	na	183	na

Appendix III

Sentences: Prepositions *in, on, at*	**KF Stem**	**KF Inflected**	**CHILDES Stem**	**CHILDES Inflected**
Sentence Set C well-formed, Set D ill-formed				
Last week, Tom **cooked** ***in*** the shiny new kitchen	47	10	213	64
Yesterday, I **hid** ***in*** the downstairs cupboard	22	6	237	10
Yesterday, Sue **fainted** ***in*** the school playground	25	1	355	50
Last week, Tom dropped a **brick** ***on*** his smelly foot	18	na	25	na
Yesterday, I patted my **dog** ***on*** the head	75	na	989	na
Yesterday, I **slipped** ***on*** the wet pavement	19	32	46	23
Yesterday, Jane **screamed** ***at*** the scary green monster	13	17	39	8
Yesterday, the baby **smiled** ***at*** everyone in the room	58	71	41	4
Last week, Sue **waited** ***at*** the bus-stop for the bus	94	70	2422	10
Last week, Dad turned off the **lights** ***at*** bedtime	333	47	505	111
Sentence Set C ill-formed, Set D well-formed				
Last week, I put the **prize** ***in*** my special secret box	28	na	22	na
Last week, the planes **landed** ***in*** the new airport	217	15	90	26
Yesterday, Tom saw **plums** ***in*** the fruit-basket	1	0	2	3
Yesterday, there were **socks** ***in*** the laundry basket	4	1	34	101
Yesterday, Tom put **sugar** ***on*** his crunchy cornflakes	34	na	254	na
Yesterday, I **yawned** a lot ***in*** the afternoon	2	0	1	1
Last week, Jane **called** Amy ***on*** the phone	188	401	754	522
Yesterday, Jane **waved** ***at*** the people on the train	46	16	29	7
Last week, I **looked** ***at*** some beautiful pictures	399	367	6861	187
Last week, we **laughed** ***at*** all the funny jokes	28	51	86	34

Bibliography

Adams, A. M., & Gathercole, S. E. (1995). Phonological working memory and speech production in preschool children. *Journal of Speech and Hearing Research, 38*, 403-414.

Adams, C., & Bishop, D. V. M. (2002). *Genetic influences on verb morphology deficits in a sample of 6-year-old twins.* Paper presented at the Symposium on Research in Child Language Disorders, Madison, Wisconsin.

Albertini, J. (1980). The acquisition of five grammatical morphemes: Deviance or delay? *Proceedings of the Symposium on Research in Child Language Disorders, 1*, 94-111. Madison: University of Wisconsin, Madison.

Amitay, S., & Ahissar, M. (2001). *Magnocellular processing and reading disability.* Paper presented at the Sensory bases of reading and language disorders, Colchester, UK.

Aram, D., & Nation, J. (1975). Patterns of language behavior in children with developmental language disorders. *Journal of Speech and Hearing Research, 18*, 229-241.

Badcock, D., & Lovegrove, W. (1981). The effects of contrast, stimulus duration, and spatial frequency on visible persistence in normal and specifically disabled readers. *Journal of Experimental Psychology: Human Perception and Performance, 7*(3), 495-505.

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

Baldeweg, T., Richardson, A., Watkins, S., Foale, C., & Gruzelier, J. (1999). Impaired auditory frequency discrimination in dyslexia detected with mismatch evoked potentials. *Annals of Neurology, 45*, 495-503.

Bates, E., & MacWhinney, B. (1987). Competition, variation, and language learning. In B. MacWhinney (Ed.), *Mechanisms of language acquisition* (pp. 157-193). Hillsdale, NJ: Lawrence Erlbaum Associates.

Beck, M. L. (1997). Regular verbs, past tense and frequency: tracking down a potential source of NS/NNS competence differences. *Second Language Research, 13*, 93-115.

Bedore, L. M., & Leonard, L. B. (2001). Grammatical morphology deficits in Spanish-speaking children with specific language impairment. *Journal of Speech, Language, and Hearing Research, 44*(4), 905-924.

Beitchman, J. H., Brownlie, E. B., & Wilson, B. (1996). Linguistic impairment and psychiatric disorder: Pathways to outcome. In J. H. Beitchman & N. J. Cohen & M. M. Konstantareas & R. Tannock (Eds.), *Language, learning, and behavior disorders: Developmental, biological, and clinical perspectives* (pp. 582). Cambridge: Cambridge University Press.

Beitchman, J. H., Hood, J., & Inglis, A. (1990). Psychiatric risk in children with speech and language disorders. *Journal of Abnormal Child Psychology, 18*(3), 283-296.

Beitchman, J. H., Nair, R., Clegg, M., Ferguson, B., & Patel, P. G. (1986). Prevalence of psychiatric disorders in children with speech and language disorders. *Journal of the American Academy of Child Psychiatry, 25*(4), 528-535.

Berko, J. (1958). The child's learning of English morphology. *Word, 14*, 150-177.

Bernstein, L. E., & Stark, R. E. (1985). Speech perception development in language-impaired children: A 4-year follow-up study. *Journal of Speech and Hearing Disorders, 50*, 21-30.

Best, M., & Demb, J. B. (1999). Normal planum temporale asymmetry in dyslexics with a magnocellular pathway deficit. *NeuroReport, 10*, 607-612.

Bird, J., Bishop, D. V. M., & Freeman, N. (1995). Phonological awareness and literacy development in children with expressive phonological impairments. *Journal of Speech and Hearing Research, 38*, 446-462.

Bishop, D. V. M. (1982). Comprehension of spoken, written, and signed sentences in childhood language disorders. *Journal of Child Psychology and Psychiatry, 23*, 1-20.

Bishop, D. V. M. (1989). Test for Reception of Grammar. Age and Cognitive Performance Centre, University of Manchester, M13 9PL: Author.

Bishop, D. V. M. (1990). Handedness, clumsiness and developmental language disorders. *Neuropsychologia, 28*, 681-690.

Bishop, D. V. M. (1994). Grammatical errors in specific language impairment: Competence or performance limitations? *Applied Psycholinguistics, 15*(4), 507-550.

Bishop, D. V. M. (1997). *Uncommon understanding: Development and disorders of language comprehension in children* (First ed.). Bath: Psychology Press Limited.

Bishop, D. V. M. (1997). Cognitive neuropsychology and developmental disorders: Uncomfortable bedfellows. *The Quarterly Journal of Experimental Psychology: Human Experimental Psychology, 50A*(4), 899-923.
Bishop, D. V. M. (1998). Development of the Children's Communication Checklist (CCC): A method for assessing qualitative aspects of communicative impairment in children. *Journal of Child Psychology and Psychiatry, 39*, 879-891.
Bishop, D. V. M. (2001). Genetic influences on language impairment and literacy problems in children: same or different? *Journal of Child Psychology and Psychiatry, 42*(2), 189-198.
Bishop, D. V. M. (2001). *Variability between and within studies: what does it mean?* Paper presented at the Sensory bases of reading and language disorders, Colchester, UK.
Bishop, D. V. M. (in press). Cerebellar abnormalities in developmental dyslexia: cause, correlate or consequence? *Cortex.*
Bishop, D. V. M., & Adams, C. (1990). A prospective study of the relationship between specific language impairment, phonological disorders and reading retardation. *Journal of Child Psychology and Psychiatry, 31*(7), 1027-1050.
Bishop, D. V. M., Bishop, S. J., Bright, P., James, C., Delaney, T., & Tallal, P. (1999). Different origin of auditory and phonological processing problems in children wtih language impairment: evidence from a twin study. *Journal of Speech, Language, and Hearing Research, 42*, 155-168.
Bishop, D. V. M., Bright, P., James, C., Bishop, S. J., & Lely, H. K. J. v. d. (2000). Grammatical SLI: A distinct subtype of developmental language impairment? *Applied Psycholinguistics, 21*(2), 159-181.
Bishop, D. V. M., Carlyon, R. P., Deeks, J. M., & Bishop, S. J. (1999). Auditory temporal processing impairment: Neither necessary nor sufficient for causing language impairment in children. *Journal of Speech, Language and Hearing Research, 42*, 1295-1310.
Bishop, D. V. M., & Edmundson, A. (1987). Language-impaired four-year-olds: Distinguishing transient from persistent impairment. *Journal of Speech and Hearing Disorders, 52*, 156-173.
Bishop, D. V. M., Jancey, C., & Steel, A. M. (1979). Orthoptic status and reading disability. *Cortex, 15*, 659-666.
Bishop, D. V. M., & Norbury, C. F. (2002). Exploring the borderlands of autistic disorder and specific language impairment: a study using standardised diagnostic instruments. *Journal of Child Psychology and Psychiatry, 43*(7), 1-13.
Bishop, D. V. M., North, T., & Donlan, C. (1996). Nonword repetition as a behavioural marker for inherited language impairment: Evidence from a twin study. *Journal of Child Psychology and Psychiatry, 37*, 391-403.
Bishop, D. V. M., & Rosenbloom, L. (1987). Classification of childhood language disorders. In W. Yule & M. Rutter (Eds.), *Language development and disorders. Clinics in Developmental Medicine (double issue)* (pp. 16-41). London: MacKeith Press.
Blackwell, A., & Bates, E. (1995). Inducing agrammatic profiles in normals: Evidence for the selective vulnerability of morphology under cognitive resource limitation. *Journal of Cognitive Neuroscience, 7*(2), 228-257.
Bliss, L. (1988). The development of modals. *The Journal of Applied Developmental Psychology, 9*, 253-261.
Blumstein, S. E., Katz, B., Goodglass, H., Shrier, R., & Dworetsky, B. (1985). The effects of slowed speech on auditory comprehension in aphasia. *Brain and Language, 24*(2), 246-265.
Bortolini, U., & Leonard, L. B. (1996). Phonology and grammatical morphology in specific language impairment: Accounting for individual variation in English and Italian. *Applied Psycholinguistics, 17*, 85-104.
Bortolini, U., Leonard, L. B., & Caselli, M. C. (1998). Specific language impairment in Italian and English: Evaluating alternative accounts of grammatical deficits. *Language and Cognitive Processes, 13*(1), 1-20.
Bottari, P., Cipriani, P., & Chilosi, A. (1995). *Past participle agreement and root infinitives in Italian children.* Paper presented at the Boston University Conference on Language Development, Boston.
Botting, N., & Conti-Ramsden, G. (2001). Non-word repetition and language development in children with specific language impairment (SLI). *International Journal of Language and Communication Disorders, 36*(4), 421-432.

Braddick, O. J. (1998). Motion processing: From elementary signals to global organisation. *Perception, 27,* S1.

Braddick, O. J., O'Brien, J. M. D., Wattam-Bell, J., Atkinson, J., & Turner, R. (2000). Form and motion coherence activate independent, but not dorsal/ventral segregated, networks in the human brain. *Current Biology, 10,* 731-734.

Bradley, L., & Bryant, P. E. (1978). Difficulties in auditory organisation as a possible cause of reading backwardness. *Nature, 271,* 746-747.

Bradley, L., & Bryant, P. E. (1983). Categorizing sounds and learning to read - a causal connection. *Nature, 301*(3 February), 419-421.

Brannan, J. R., & Williams, M. C. (1987). Allocation of visual attention in good and poor readers. *Perception and Psychophysics, 41*(1), 23-28.

Breitmeyer, B. G. (1980). Unmasking visual masking: A look at the "why" behind the veil of "how". *Psychological Review, 87*(1), 52-69.

Breitmeyer, B. G., Levi, D. M., & Harwerth, R. S. (1981). Flicker masking in spatial vision. *Vision Research, 21*(9), 1377-1385.

Bridgeman, E., & Snowling, M. (1988). The perception of phoneme sequence: A comparison of dyspraxic and normal children. *British Journal of Disorders of Communication, 23,* 245-252.

Briscoe, J., Bishop, D. V. M., & Norbury, C. F. (2001). Phonological processing, language, and literacy: A comparison of children with mild-to-moderate sensorineural hearing loss and those with specific language impairment. *Journal of Child Psychology and Psychiatry, 42*(3), 329-340.

Briscoe, J., Gathercole, S. E., & Marlow, N. (1998). Short-term memory and language outcomes after extreme prematurity at birth. *Journal of Speech, Language and Hearing Research, 41*(3), 654-666.

Britten, K., Shadlen, M., Newsome, W., & Movshon, J. (1992). The analysis of visual motion: a comparison of neuronal and psychophysical performance. *Journal of Neuroscience, 12,* 4745-4765.

Brown, R. W. (1973). *A first language: The early stages.* Cambridge, MA: Harvard University Press.

Burleigh, J. M. (1997). Time-rate speech expansion and central auditory nervous system function. *Dissertation Abstracts International: Section B: The Sciences and Engineering, 57*(7-B), 4279.

Bybee, J. L., & Slobin, D. I. (1982). Rules and schemas in the development and use of the Engish past tense. *Language, 58,* 265-289.

Campbell, T., & McNeil, M. (1985). Effects of presentation rate and divided attention on auditory comprehension in children with an acquired language disorder. *Journal of Speech and Hearing Research, 28,* 513-520.

Caplan, D. (1981). On the cerebral organization of linguistic functions: Logical and empirical issues surrounding deficit analysis and functional localization. *Brain and Language, 14,* 120-137.

Caplan, D., Baker, C., & Dehaut, F. (1985). Syntactic determinants of sentence comprehension in aphasia. *Cognition, 21,* 117-175.

Caramazza, A., & Zurif, E. B. (1976). Dissociation of algorithmic and heuristic processes in language comprehension: Evidence from aphasia. *Brain and Language, 3*(4), 572-582.

Carpenter, P. A., & Just, M. A. (1989). The role of working memory in language comprehension. In D. Klahr & K. Kotovsky (Eds.), *Complex information processing: The impact of Herbert A. Simon* (pp. 31-68). Hillsdale, NJ: Lawrence Erlbaum Associates.

Carterette, E. C., & Jones, M. H. (1974). *Informal speech: Alphabetic and phonemic texts with statistical analyses and tables.* Berkeley, CA: University of California Press.

Castles, A., & Coltheart, M. (1993). Varieties of developmental dyslexia. *Cognition, 47,* 149-180.

Catts, H. W. (1993). The relationship between speech-language impairments and reading disabilities. *Journal of Speech and Hearing Research, 36*(5), 948-958.

Charles-Luce, J., & Luce, P. A. (1990). Similarity neighbourhoods of words in young children's lexicons. *Journal of Child Language, 17,* 205-215.

Chiat, S. (2001). Mapping theories of developmental language impairment: Premises, preditions and evidence. *Language and Cognitive Processes, 16*(2/3), 113-142.

Chomsky, N. (1981). *Lectures on government and binding.* Dordrecht, The Netherlands: Foris.

Chomsky, N. (1986). *Knowledge of language: Its nature, origin and use.* New York: Praeger.

Cipriani, P., Chilosi, A., Bottari, P., Pfanner, L., Poli, P., & Sarno, S. (1991). L'uso della morfologia grammaticale nella disfasia congenita. *Giornale Italiano di Psicologia, 18,* 765-779.

Clahsen, H. (1989). The grammatical characterization of developmental dysphasia. *Linguistics, 27,* 897-

920.
Clahsen, H., Rothweiler, M., Woest, A., & Marcus, G. (1992). Regular and irregular inflection in the acquisition of German plurals. *Cognition, 45*, 225-255.
Consortium, T. S. (2002). A genomewide scan identifies two novel loci involved in specific language impairment. *American Journal of Human Genetics, 70*, 384-398.
Conti-Ramsden, G., Crutchley, A., & Botting, N. (1997). The extent to which psychometric tests differentiate subgroups of children with specific language impairment. *Journal of Speech, Language and Hearing Research, 40*, 765-777.
Cornelissen, P., Richardson, A., Mason, A., Fowler, S., & Stein, J. (1995). Contrast sensitivity and coherent motion detection measured at photopic luminance levels in dyslexics and controls. *Vision Research, 35*(10), 1483-1494.
Cornelissen, P. L., Hansen, P. C., Hutton, J. L., Evangelinou, V., & Stein, J. F. (1998). Magnocellular visual function and children's single word reading. *Vision Research, 38*(3), 471-482.
Csepe, V. (1995). On the origin and development of the mismatch negativity. *Ear and Hearing, 16*, 91-104.
Dalalakis, J. E. (1999). Morphological representation in specific language impairment: Evidence from Greek word formation. *Folia Phoniatrica et Logopaedica, 51*, 20-35.
Daneman, M., & Carpenter, P. A. (1980). Individual differences in working memory and reading. *Journal of Verbal Learning and Verbal Behaviour, 19*, 450-466.
Daneman, M., & Carpenter, P. A. (1983). Individual differences in integrating information between and within sentences. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 9*, 561-584.
de Villiers, J. G., & de Villiers, P. A. (1973). A cross-sectional study of the acquisition of grammatical morphemes in child speech. *Journal of Psycholinguistic Research, 2*(3), 267-278.
de Weirdt, W. (1988). Speech perception and frequency discrimination in good and poor readers. *Applied Psycholinguistics, 9*, 163-183.
Demb, J. B., Boynton, G. M., & Heeger, D. J. (1998). Functional magnetic resonance imaging of early visual pathways in dyslexia. *Journal of Neuroscience, 18*(17), 6939-6951.
Dick, F., Bates, E., Wulfeck, B., Utman, J. A., Dronkers, N., & Gernsbacher, M. A. (2001). Language deficits, localization, and grammar: Evidence for a distributive model of language breakdown in aphasic patients and neurologically intact individuals. *Psychological Review, 108*(4), 759-788.
Dollaghan, C., & Campbell, T. F. (1998). Nonword repetition and child language impairment. *Journal of Speech, Language, and Hearing Research, 41*, 1136-1146.
Dromi, E., Leonard, L. B., Adam, G., & Zadunaisky-Ehrlich, S. (1999). Verb agreement morphology in Hebrew-speaking children with specific language impairment. *Journal of Speech, Language, and Hearing Research, 42*, 1414-1431.
Dromi, E., Leonard, L. B., & Shteiman, M. (1993). The grammatical morphology of Hebrew-speaking children with specific language impairment: Some competing hypotheses. *Journal of Speech and Hearing Research, 36*, 760-771.
Drullman, R. (1995). Temporal envelope and fine structure cues for speech intelligibility. *Journal of the Acoustical Society of America, 97*(1), 585-592.
Drullman, R., Festen, J. M., & Plomp, R. (1994a). Effect of temporal envelope smearing on speech reception. *Journal of the Acoustical Society of America, 95*(2), 1053-1064.
Drullman, R., Festen, J. M., & Plomp, R. (1994b). Effect of reducing slow temporal modulations on speech reception. *Journal of the Acoustical Society of America, 95*(5), 2670-2680.
Dunn, L. M., Dunn, L. M., Whetton, C., & Pintilie, D. (1982). British Picture Vocabulary Scale - long form. Windsor, U.K.: NFER-Nelson.
Eden, G. F., VanMeter, J. W., Rumsey, J. M., Maisog, J. M., Woods, R. P., & Zeffiro, T. A. (1996). Abnormal processing of visual motion in dyslexia revealed by functional brain imaging. *Nature, 382*, 66-69.
Ellis Weismer, S., & Hesketh, L. J. (1993). The influence of prosodic and gestural cues on novel word acquisition by children with specific language impairment. *Journal of Speech and Hearing Research, 36*, 1013-1025.
Ellis Weismer, S., & Hesketh, L. J. (1996). Lexical learning by children with specific language impairment: Effects of linguistic input presented at varying speaking rates. *Journal of Speech and Hearing Research, 39*(1), 177-190.
Ellis Weismer, S., Tomblin, J. B., Zhang, X., Buckwalter, P., Chynoweth, J. G., & Jones, M. (2000).

Nonword repetition performance in school-age children with and without language impairment. *Journal of Speech, Language, and Hearing Research, 43*(4), 865-878.
Elman, J. L., Bates, E. A., Johnson, M. H., Karmiloff-Smith, A., Parisi, D., & Plunkett, K. (1996). *Rethinking innateness: A connectionist perspective on development* (First ed. Vol. 10). Cambridge, Massachusetts; London: A Bradford Book, The MIT Press.
Eyer, J., & Leonard, L. B. (1995). Functional categories and specific language impairment: A case study. *Language Acquisition, 4*, 177-203.
Farmer, M. E., & Klein, R. M. (1995). The evidence for a temporal processing deficit linked to dyslexia: A review. *Psychonomic Bulletin & Review, 2*(4), 460-493.
Fee, E. J. (1995). The phonological system of a specifically language-impaired population. *Clinical Linguistics and Phonetics, 9*, 189-209.
Felbaum, C., Miller, S., Curtiss, S., & Tallal, P. (1995). An auditory processing deficit as a possible source of SLI. In D. MacLaughlin & S. McEwan (Eds.), *Proceedings of the 19th Annual Boston University Conference on Language Development* (Vol. 1, pp. 204-215): Cascadilla Press.
Fisher, S. E., Francks, C., Marlow, A. J., Macphie, I. L., Newbury, D. F., Cardon, L. R., Ishikawa-Brush, Y., Richardson, A. J., Talcott, J. B., Gayan, J., Olson, R. K., Pennington, B. F., Smith, S. D., DeFries, J. C., Stein, J. F., & Monaco, A. P. (2002). Independent genome-wide scans identifying a chromosome 18 quantitative-trait locus influencing dyslexia. *Nature Genetics, 30*, 86-91.
Fletcher, P. (1992). Sub-groups in school-age language-impaired children. In P. Fletcher & D. Hall (Eds.), *Specific speech and language disorders in children* (pp. 152-163). London: Whurr.
Fletcher, P., & Garman, M. (1988). Normal language development and language impairment: Syntax and beyond. *Clinical Linguistics and Phonetics, 2*, 97-114.
Fodor, J. A. (1983). *The modularity of mind: An essay on faculty psychology*. Cambridge, MA: Bradford Books.
Friederici, A. D., & Graetz, R. (1984). *Processing passive sentences in aphasia: Deficits and strategies.* Paper presented at the Seventh INS European Conference, Aachen.
Frith, U. (1989). *Autism: Explaining the enigma.* Oxford: Blackwell Science.
Galaburda, A. M., Menard, M. T., & Rosen, G. D. (1994). Evidence for aberrant auditory anatomy in developmental dyslexia. *Proceedings of the National Academy of Science of the United States of America, 91*, 8010-8013.
Gallagher, A., Frith, U., & Snowling, M. J. (2000). Precursors of literacy delay among children at genetic risk of dyslexia. *Journal of Child Psychology and Psychiatry, 41*(2), 203-213.
Garvey, C. (1979). An approach to the study of children's role play. *The Quarterly Newsletter of the Laboratory of Human Cognition, 12.*
Gathercole, S., & Baddeley, A. (1990). Phonological memory deficits in language disordered children: Is there a causal connection? *Journal of Memory and Language, 29*, 336-360.
Gathercole, S., & Baddeley, A. (1993). *Working memory and language.* Hillsdale, NJ: Lawrence Erlbaum Associates.
Gathercole, S. E., & Baddeley, A. D. (1996). The Children's Test of Nonword Repetition. London: Psychological Corporation.
Gathercole, S. E., Service, E., Hitch, G. J., Adams, A. M., & Martin, A. J. (1999). Phonological short-term memory and vocabulary development: Further evidence on the nature of the relationship. *Applied Cognitive Psychology, 13*(1), 65-77.
Gathercole, S. E., Willis, C. S., Baddeley, A. D., & Emslie, H. (1994). The children's test of nonword repetition: A test of phonological working memory. *Memory, 2*(2), 103-127.
Gathercole, S. E., Willis, C. S., Emslie, H., & Baddeley, A. D. (1992). Phonological memory and vocabulary development during the early school years: A longitudinal study. *Developmental Psychology, 28*(5), 887-898.
Gathercole, V. (1980). *Birdies like birdseed bester than buns: A study of relational comparatives and their acquisition.* Unpublished doctoral dissertation. University of Kansas.
Gavin, W., Klee, T., & Membrino, I. (1993). Differentiating specific language impairment from normal language development using grammatical analysis. *Clinical Linguistics and Phonetics, 7*(191-206).
Gelfand, S. A. (1998). *Hearing: An introduction to psychological and physiological acoustics* (3 ed.). New York: Marcel Dekker.
Gerken, L. A., & McIntosh, B. J. (1993). The interplay of grammatical morphemes and prosody in early

language. *Developmental Psychology, 29*, 448-457.
Gillam, R. B., Loeb, D. F., & Friel-Patti, S. (2001). Looking back: A summary of five exploratory studies of Fast ForWord. *American Journal of Speech-Language Pathology, 10*, 269-273.
Gleason, J. B. (1980). The acquisition of social speech and politeness formulae. In H. Giles & W. P. Robinson & S. M. P. (Eds.), *Language: Social psychological perspectives*. Oxford: Pergamon.
Goad, H., & Rebellati, C. (1994). Pluralization in familial language impairment: Affixation or compounding? *McGill Working Papers in Linguistics, 10*, 24-40.
Gopnik, M. (1990). Feature-blind grammar and dysphasia. *Nature, 344*(19 April), 715.
Gopnik, M., & Crago, M. (1991). Familial aggregation of a developmental language disorder. *Cognition, 39*, 1-50.
Gopnik, M., Dalalakis, J., Fukuda, S. E., Fukuda, S., & Kehayia, E. (1996). Genetic language impairment: Unruly grammars. In W. G. Runciman & J. Maynard Smith & R. I. M. Dunbar (Eds.), *Evolution of Social Behaviour Patterns in Primates and Man* (Vol. 88, pp. 297). Oxford: Oxford University Press.
Goulandris, N. K., Snowling, M. J., & Walker, I. (2000). Is dyslexia a form of specific language impairment? A comparison of dyslexic and language impaired children as adolescents. *Annals of Dyslexia, 50*, 103-120.
Green, D. M. (1964). General prediction relating yes-no and forced choice results. *Journal of the Acoustical Society of America, 36*, 10-42.
Green, G. G. R. (1976). *Temporal Aspects of Audition*. University of Oxford, Oxford.
Griffiths, Y. M., Hill, N. I., Bailey, P. J., & Snowling, M. J. (2001). *Binaural unmasking and temporal order discrimination in adult dyslexics*. Paper presented at the Sensory bases of reading and language disorders, Colchester, UK.
Grimshaw, J., & Pinker, S. (1989). Positive and negative evidence in language acquisition. *Brain and Behavioral Sciences, 12*, 341.
Guilfoyle, E., Allen, S., & Moss, S. (1991). *Specific language impairment and hte maturation of functional categories*. Paper presented at the Boston University Conference on Language Development, Boston.
Hall, W. S., Nagy, W. E., & Linn, R. (1984). *Spoken words*. Hillsdale, NJ: Lawrence Erlbaum Associates.
Hansen, P. C., Stein, J. F., Orde, S. R., Winter, J. L., & Talcott, J. B. (2001). Are dyslexics' visual deficits limited to measures of dorsal stream function? *NeuroReport, 12*(7), 1527-1530.
Hayes, D. P. (1988). Speaking and writing: Distinct patterns of word choice. *Journal of Memory and Language, 27*, 572-585.
Heath, S., & Hogben, J. (2001). *Can auditory temporal order judgement be used as an effective measure of individual differences in dyslexics?* Paper presented at the Sensory bases of reading and language disorders, Colchester, UK.
Heath, S. M., Hogben, J. H., & Clark, C. D. (1999). Auditory temporal processing in disabled readers with and without oral language delay. *Journal of Child Psychology and Psychiatry, 40*(4), 637-647.
Hill, N. I., Bailey, P. J., Griffiths, Y. M., & Snowling, M. J. (1999). Frequency acuity and binaural masking release in dyslexic listeners. *Journal of the Acoustical Society of America, 106*(6), L53-58.
Howell, D. C. (1997). *Statistical methods for psychology* (4 ed.). Belmont, CA: Duxbury Press.
Hughes, M., & Sussman, H. (1983). An assessment of cerebral dominance in language-disordered children via a time-sharing paradigm. *Brain and Language, 19*, 48-64.
Hurst, J., Baraitser, M., Auger, E., Graham, F., & Norell, S. (1990). An extended family with a dominantly inherited speech disorder. *Neurology, 32*, 347-355.
James, D., van Steenbrugge, W., & Chiveralls, K. (1994). Underlying deficits in language-disordered children with central auditory processing difficulties. *Applied Psycholinguistics, 15*, 311-328.
Jeffress, L. A., Blodgett, H. C., Sandel, T. T., & wood, C. L. (1956). Masking of tonal signals. *Journal of the Acoustical Society of America, 28*, 416-426.
Jenner, A. R., Rosen, G. D., & Galaburda, A. M. (1999). Neuronal asymmetries in primary visual cortex of dyslexic and nondyslexic brains. *Annals of Neurology, 46*(2), 189-196.
Jensen, J. K., & Neff, D. L. (1993). Development of basic auditory discrimination in preschool children. *Psychological Science, 4*(2), 104-107.
Joanisse, M. F., & Seidenberg, M. S. (1998). Specific language impairment: A deficit in grammar or processing? *Trends in Cognitive Sciences, 2*(7), 240-247.
Johnston, J., & Ellis Weismer, S. (1983). Mental rotation abilities in language-disordered children. *Journal*

of Speech and Hearing Research, 26, 397-403.
Just, M. A., & Carpenter, P. A. (1992). A capacity theory of comprehension: Individual differences in working memory. *Psychological Review, 99*, 122-149.
Kaernbach, C. (1991). Simple adaptive testing with the weighted up-down method. *Perception and Psychophysics, 49*(3), 227-229.
Kail, R. (1994). A method for studying the generalized slowing hypothesis in children with specific language impairment. *Journal of Speech and Hearing Research, 37*(2), 418-421.
Kail, R., & Salthouse, T. (1994). Processing speed as a mental capacity. *Acta Psychologica, 86*, 199-225.
Kamhi, A. G., & Catts, H. W. (1986). Toward and understanding of developmental language and reading disorders. *Journal of Speech and Hearing Disorders, 51*(337-347).
Kamhi, A. G., Catts, H. W., Mauer, D., Apel, K., & Gentry, B. F. (1988). Phonological and spatial processing abilities in language- and reading-impaired children. *Journal of Speech and Hearing Disorders, 53*, 316-327.
Kamhi, A. G., & Koenig, L. A. (1985). Metalinguistic awareness in normal and language-disordered children. *Language, Speech, and Hearing Services in Schools, 16*(3), 199-210.
Kaufman, A. S., & Kaufman, N. L. (1983). *Kaufman Assessment Battery for Children.* Circle Pines, MN: American Guidance Service.
Kay, R. H. (1982). Hearing of modulation in sounds. *Physiological Reviews, 62*(3), 894-975.
Kay, R. H., & Matthews, D. R. (1972). On the existence in human auditory pathways of channels selectively tuned to the modulation present in frequency-modulated tones. *Journal of Physiology, 225*, 657-677.
Kilborn, K. (1991). Selective impairment of grammatical morphology due to induced stress in normal listeners: Implications for aphasia. *Brain and Language, 41*(2), 275-288.
King, G., Schelletter, I., Sinka, P., Fletcher, P., & Ingham, R. (1995). Are English-speaking SLI children with morpho-syntactic deficits impaired in their use of locative-contact and causative alternating verbs? *University of Reading Working Papers in Linguistics, 2*, 45-65.
Kinsbourne, M., Rufo, D. T., Gamzu, E., Palmer, R. L., & Berliner, A. K. (1991). Neuropsychological deficits in adults with dyslexia. *Developmental Medicine & Child Neurology, 33*, 763-775.
Kovac, I., Barabedian, B., Souich, C. D., & Palmour, R. M. (2001). Attention deficit/hyperactivity in SLI children increases risk of speech/language disorders in first-degree relatives: A preliminary report. *Journal of Communication Disorders, 34*, 339-354.
Kucera, H., & Francis, W. N. (1967). *Computational analysis of present-day American English.* Providence, RI: Brown University Press.
Kuczaj, S. (1976). *-ing, -s and -ed: A study of the acquisition of certain verb inflections.* Unpublished doctoral dissertation. University of Minnesota.
Lahey, M., & Edwards, J. (1996). Why do children with specific language impairment name pictures more slowly than their peers? *Journal of Speech and Hearing Research, 39*, 1081-1098.
Lasky, E. Z., Weidner, W. E., & Johnson, J. P. (1976). Influence of linguistic complexity, rate of presentation, and interphrase pause time on auditory-verbal comprehension of adult aphasic patients. *Brain and Language, 3*, 386-395.
Leitao, S., Hogben, J., & Fletcher, J. (1997). Phonological processing skills in speech and language impaired children. *European Journal of Disorders of Communication, 32*(2), 73-93.
Leonard, C. M., Eckert, M. A., Lombardino, L. J., Oakland, T., Kranzler, J., Mohr, C. M., King, W. M., & Freeman, A. (2001). Anatomical risk factors for phonological dyslexia. *Cerebral Cortex, 11*(2), 148-157.
Leonard, L. B. (1989). Language learnability and specific language impairment in children. *Applied Psycholinguistics, 10*, 179-202.
Leonard, L. B. (1995). Functional categories in the grammars of children with specific language impairment. *Journal of Speech and Hearing Research, 38*, 1270-1283.
Leonard, L. B. (1998). *Children with specific language impairment* (First ed. Vol. 13). Cambridge, Massachusetts; London: The MIT Press. A Bradford Book.
Leonard, L. B., Bortolini, U., Caselli, M. C., McGregor, K., & Sabbadini, L. (1992). Morphological deficits in children with specific language impairment: The status of features in the underlying grammar. *Language Acquisition, 2*, 151-179.
Leonard, L. B., Dromi, E., Adam, G., & Zadunaisky-Ehrlich, S. (2000). Tense and finiteness in the speech of children with specific language impairment acquiring Hebrew. *International Journal of*

Language and Communication Disorders, 35, 319-335.
Leonard, L. B., & Eyer, J. (1996). Surface properties of grammatical morphology and morphological deficits in children with specific language impairment. In J. Morgan & K. Demuth (Eds.), *Signal to syntax* (pp. 233-247). Hillsdale, NJ: Lawrence Erlbaum Associates.
Leonard, L. B., McGregor, K. K., & Allen, G. D. (1992). Grammatical morphology and speech perception in children with specific language impairment. *Journal of Speech and Hearing Research, 35*(October), 1076-1085.
Leonard, L. B., Nippold, M., Kail, R., & Hale, C. (1983). Picture naming in language-impaired children. *Journal of Speech and Hearing Research, 26*, 609-615.
Liberman, I. Y., & Shankweiler, D. (1985). Phonology and the problems of learning to read and write. *Remedial and Special Education, 6*, 8-17.
Lincoln, A. J., Dickstein, P., Courchesne, E., Elmasian, R., & Tallal, P. (1992). Auditory processing abilities in non-retarded adolescents and young adults with developmental receptive language disorder and autism. *Brain and Language, 43*, 613-622.
Livingstone, M. S., Rosen, G. D., Drislane, F. W., & Galaburda, A. M. (1991). Physiological and anatomical evidence for a magnocellular defect in developmental dyslexia. *Proceedings of the National Academy of Science of the United States of America, 88*, 7943-7947.
Loeb, D. F., & Leonard, L. B. (1991). Subject case marking and verb morphology in normally developing and specifically language-impaired children. *Journal of Speech and Hearing Research, 34*, 340-346.
Lorenzi, C., Dumont, A., & Fullgrabe, C. (2000). Use of temporal envelope cues by children with developmental dyslexia. *Journal of Speech, Language, and Hearing Research, 43*(6), 1367-1379.
Love, A. J., & Thompson, M. G. (1988). Language disorders and attention deficit disorders in young children referred for psychiatric services: Analysis of prevalence and a conceptual synthesis. *American Journal of Orthopsychiatry, 58*(1), 52-64.
Lovegrove, W., Martin, F., & Slaghuis, W. (1986). A theoretical and experimental case for a visual deficit in specific reading disability. *Cognitive Neuropsychology, 3*(2), 225-267.
Lum, J. A. G., & Bavin, E. (2002). *An examination into grammatical knowledge and cognitive skills in children with specific language impairment.* Paper presented at the Symposium on Research in Child Language Disorders, Madison, Wisconsin.
Macmillan, N. A., & Creelman, C. D. (1991). *Detection theory: A user's guide.* Cambridge: Cambridge University Press.
MacWhinney, B., & Bates, E. (Eds.). (1989). *The crosslinguistic study of sentence processing.* Cambridge: Cambridge University Press.
Mann, V. A. (1984). Longitudinal prediction and prevention of early reading difficulty. *Annals of Dyslexia, 34*, 117-136.
Marchman, V. A., Wulfeck, B., & Weismer, S. E. (1999). Morphological productivity in children with normal language and SLI: A study of the English past tense. *Journal of Speech, Language, and Hearing Research, 42*, 206-219.
Marcus, G. F., Pinker, S., Ullman, M., Hollander, M., Rosen, T., & Xu, F. (1992). Overregularization in language acquisition. *Monographs of the Society for Research in Child Development, 57(Serial no. 58).*
Marslen-Wilson, W. D. (2002). Personal communication. Meeting of the Experimental Psychology Society, London.
Martin, F., & Lovegrove, W. (1984). The effects of field size and luminance on contrast sensitivity differences between specifically reading disabled and normal children. *Neuropsychologia, 22*, 73-77.
Martin, F., & Lovegrove, W. (1987). Flicker contrast sensitivity in normal and specifically-disabled readers. *Perception, 16*, 215-221.
Massaro, D. W., & Burke, D. (1991). Perceptual development and auditory backward recognition masking. *Developmental Psychology, 27*, 85-96.
McAnally, K. I., Hansen, P. C., Cornelissen, P. L., & Stein, J. F. (1997). Effect of time and frequency manipulation on syllable perceptiốn in developmental dyslexics. *Journal of Speech, Language and Hearing Research, 40*(4), 912-924.
McAnally, K. I., & Stein, J. F. (1996). Auditory temporal coding in dyslexia. *Proceedings of the Royal Society, Part B, 263*, 961-965.

McAnally, K. I., & Stein, J. F. (1997). Scalp potentials evoked in amplitude-modulated tones in dyslexia. *Journal of Speech, Language, and Hearing Research, 40*(4), 939-945.

McArthur, G. M., & Hogben, J. H. (2001). Auditory backward recognition masking in children with a specific language impairment and children with a specific reading disability. *Journal of the Acoustical Society of America, 109*(3), 1092-1100.

McArthur, G. M., Hogben, J. H., Edwards, V. T., Heath, S. M., & Mengler, E. D. (2000). On the "specifics" of specific reading disability and specific language impairment. *Journal of Child Psychology and Psychiatry, 41*(7), 869-874.

McCroskey, R. L., & Thompson, N. W. (1973). Comprehension of rate controlled speech by children with specific learning disabilities. *Journal of Learning Disabilities, 6*, 621-628.

McNamara, M., Carter, A., McIntosh, B., & Gerken, L. (1998). Sensitivity to grammatical morphemes in children with specific language impairment. *Journal of Speech, Language, and Hearing Research, 41*, 1147-1157.

Meints, K., Plunkett, K., Harris, P. L., & Dimmock, D. (2002). What is 'on' and 'under' for 15-, 18- and 24-month-olds? Typicality effects in early comprehension of spatial prepositions. *British Journal of Developmental Psychology, 20*, 113-120.

Menell, P., McAnally, K. I., & Stein, J. F. (1999). Psychophysical sensitivity and physiological response to amplitude modulation in adult dyslexic listeners. *Journal of Speech, Language and Hearing Research, 42*(4), 797-803.

Merigan, W. H., & Maunsell, J. H. (1990). Macaque vision after magnocellular lateral geniculate lesions. *Visual Neuroscience, 5*, 347-352.

Merzenich, M. M., Jenkins, W. M., Johnston, P., Schreiner, C., Miller, S. L., & Tallal, P. (1996). Temporal processing deficits of language-learning impaired children ameliorated by training. *Science, 271*(5 January), 77-81.

Miller, C. A., Kail, R., Leonard, L. B., & Tomblin, J. B. (2001). Speed of processing in children with specific language impairment. *Journal of Speech, Language, and Hearing Research, 44*(2), 416-433.

Milne, E., Swettenham, J., Hansen, P., Campbell, R., Jeffries, H., & Plaisted, K. (2002). High motion coherence thresholds in children with autism. *Journal of Child Psychology and Psychiatry, 43*(2), 255-263.

Milner, D., & Goodale, M. (1995). *The visual brain in action*. Oxford: Oxford University Press.

Mishkin, M., Ungerlieder, L. G., & Macko, K. A. (1983). Object vision and spatial vision: Two cortical pathways. *Trends in Neurosciences, 6*(10), 414-417.

Miyake, A., Carpenter, P. A., & Just, M. A. (1994). A capacity approach to syntactic comprehension disorders: Making normal adults perform like aphasic patients. *Cognitive Neuropsychology, 11*(6), 671-717.

Mody, M., Studdert-Kennedy, M., & Brady, S. (1997). Speech perception deficits in poor readers: auditory processing or phonological coding? *Journal of Experimental Child Psychology, 64*, 199-231.

Montgomery, J. W. (1995). Sentence comprehension in children with specific language impairment: The role of phonological working memory. *Journal of Speech and Hearing Research, 38*, 187-199.

Montgomery, J. W. (2000). Relation of working memory to off-line and real-time sentence processing in children with specific language impairment. *Applied Psycholinguistics, 21*(1), 117-148.

Montgomery, J. W., & Leonard, L. B. (1998). Real-time inflectional processing by children with specific language impairment: Effects of phonetic substance. *Journal of Speech, Language, and Hearing Research, 41*(6), 1432-1443.

Moore, B. C. J. (1995). Frequency analysis and masking. In B. C. J. Moore (Ed.), *Hearing* (pp. 161-205). London: Academic Press.

Moore, B. C. J. (1997). *An introduction to the psychology of hearing* (4 ed.). London: Academic Press.

Moore, C., & Dunham, P. J. (1995). *Joint attention: Its origins and role in development*. Hillsdale, NJ: Lawrence Erlbaum Associates.

Moore, J. M., Wilson, W. R., & Thompson, G. (1977). Visual reinforcement of head-turn responses in infants under 12 months of age. *Journal of Speech and Hearing Disorders, 42*, 328-334.

Nichols, S., Townsend, J., & Wulfeck, B. (1995). *Covert visual attention in language-impaired children* (Technical Report CND-9502): Center for Research in Language, University of California at San Diego.

Nicolson, R. I., & Angela, F. J. (1995). Dyslexia is more than a phonological disability. *Dyslexia, 1*(1), 19-

36.
Nicolson, R. I., & Fawcett, A. J. (1990). Automaticity: A new framework for dyslexia research? *Cognition, 35*, 159-182.
Nittrouer, S. (1992). Age-related differences in perceptual effects of formant transitions within syllables and across syllable boundaries. *Journal of Phonetics, 20*, 1-32.
Nittrouer, S. (1996). Discriminability and perceptual weighting of some acoustic cues to speech perception by 3-year-olds. *Journal of Speech and Hearing Research, 39*, 278-297.
Nittrouer, S. (1999). Do temporal processing deficits cause phonological processing problems? *Journal of Speech, Language, and Hearing Research, 42*(August), 925-942.
Nittrouer, S. (1999). Do temporal processing deficits cause phonological processing problems? *Journal of Speech, Language, and Hearing Research, 42*, 925-942.
Norbury, C. F., Bishop, D. V. M., & Briscoe, J. (2001). Production of English finite verb morphology: A comparison of SLI and mild-moderate hearing impairment. *Journal of Speech, Language, and Hearing Research, 44*(1), 165-178.
Oetting, J. B., & Horohov, J. E. (1997). Past-tense marking by children with and without specific language impairment. *Journal of Speech, Language, and Hearing Research, 40*, 62-74.
Oetting, J. B., & Rice, M. L. (1993). Plural acquisition in children with specific language impairment. *Journal of Speech and Hearing Research, 36*(6), 1236-1248.
Owen, A. J., Dromi, E., & Leonard, L. B. (2001). The phonology-morphology interface in the speech of Hebrew-speaking children with specific language impairment. *Journal of Communication Disorders, 34*, 323-337.
Palmer, A. R. (1995). Neural signal processing. In B. C. J. Moore (Ed.), *Hearing* (pp. 75-121). London: Academic Press.
Palmer, A. R., & Russell, I. J. (1986). Phase-locking in the cochlear nerve of the guinea pig and its relation to the receptor potential of inner hair-cells. *Hearing Research, 24*, 1-15.
Pammer, K., & McGregor, R. (1999). *Visual and auditory processing in dyslexia: A question of degree.* Paper presented at The Experimental Psychology Conference, Sydney.
Pammer, K., & Wheatley, C. (2001). Isolating the M(y)-cell response in dyslexia using the spatial frequency doubling illusion. *Vision Research, 41*(16), 2139-2147.
Peters, A. (1985). Language segmentation: Operating principles for the perception and analysis of language. In D. I. Slobin (Ed.), *The crosslinguistic study of language acquisition 2: Theoretical issues* (pp. 1029-1067). Hillsdale, NJ: Lawrence Erlbaum Associates.
Pinker, S. (1984). *Language learnability and language development.* Cambridge, MA: Harvard University Press.
Pinker, S. (1999). *Words and rules: The ingredients of language.* London: Weidenfeld & Nicolson.
Plante, E., Swisher, L., Kierman, B., & Restrepo, M. A. (1993). Language matches: Illuminating or confounding? *Journal of Speech and Hearing Research, 36*(3), 772-776.
Plaut, D., McClelland, J. L., Seidenberg, M. S., & Patterson, K. E. (1996). Understanding normal and impaired reading: Computational principles in quasi-irregular domains. *Psychological Review, 103*, 56-115.
Plomin, R., & Dale, P. S. (2000). Genetics and early language development: A UK study of twins. In D. V. M. Bishop & L. B. Leonard (Eds.), *Speech and language impairment in children: Causes, characteristics, intervention and outcome* (pp. 35-51).
Powell, R., & Bishop, D. V. M. (1992). Clumsiness and perceptual problems in children with specific language impairment. *Developmental Medicine & Child Neurology, 34*, 755-765.
Radford, A. (1990). *Syntactic theory and the acquisition of English syntax.* Oxford: Blackwell.
Rae, C., Lee, M. A., Dixon, R. M., Blamire, A. M., Thompson, C. H., Styles, P., Talcott, J., Richardson, A. J., & Stein, J. F. (1998). Metabolic abnormalities in developmental dyslexia detected by ^{1}H magnetic resonance spectroscopy. *The Lancet, 351*(9119), 1849-1852.
Ramscar, M. (2001). *The influence of semantics on past-tense inflection.* Paper presented at the Proceedings of the 23rd Cognitive Science Society Meeting, Edinburgh.
Ramus, F., Rosen, S., Dakin, S., & Frith, U. (2001). *Sensory deficits do not play a causal role in specific reading impairment.* Paper presented at the Sensory bases of reading and language disorders, Colchester, UK.
Rapin, I., & Allen, D. (1983). Developmental language disorders: Nosologic considerations. In U. Kirk (Ed.), *Neuropsychology of language, reading, and spelling* (pp. 155-184). New York: Academic

Press.

Ratcliffe, R. (1993). Methods for dealing with reaction time outliers. *Psychological Bulletin, 114*(3), 510-532.

Raven, J. C., Court, J. H., & Raven, J. (1986). Raven's Coloured Progressive Matrices. London: H. K. Lewis.

Reed, M. A. (1989). Speech perception and the discrimination of brief auditory cues in reading-disabled children. *Journal of Experimental Child Psychology, 48*, 270-292.

Rees, A., & Moller, A. R. (1983). Responses of neurons in the inferior colliculus of the rat to AM and FM tones. *Hearing Research, 10*, 301-330.

Rees, A., & Palmer, A. R. (1989). Neuronal responses to amplitude-modulated and pure-tone stimuli in the guinea pig inferior colliculus, and their modification by broadband noise. *Journal of the Acoustical Society of America, 85*, 1978-1994.

Remez, R. E., Rubin, P. E., Pisoni, D. B., & Carrell, T. D. (1981). Speech perception without traditional speech cues. *Science, 212*, 947-950.

Rice, M., Wexler, K., & Cleave, P. (1995). Specific language impairment as a period of extended optional infinitive. *Journal of Speech and Hearing Research, 38*, 850-863.

Rice, M. L. (2000). Grammatical symptoms of specific language impairment. In D. V. M. Bishop & L. B. Leonard (Eds.), *Speech and language impairments in children: Causes, characteristics, intervention and outcome*. Hove, UK: Psychology Press.

Rice, M. L., Buhr, J., & Oetting, J. B. (1992). Specific-language-impaired children's quick incidental learning of words: The effect of a pause. *Journal of Speech and Hearing Research, 35*, 1040-1048.

Rice, M. L., & Oetting, J. B. (1993). Morphological deficits of children with SLI: Evaluation of number marking and agreement. *Journal of Speech and Hearing Research, 36*(6), 1249-1257.

Rice, M. L., & Wexler, K. (1996). A phenotype of specific language impairment: Extended optional infinitives. In M. L. Rice (Ed.), *Toward a genetics of language* (pp. 215-237). Mahwah, NJ: Lawrence Erlbaum.

Rice, M. L., Wexler, K., & Hershberger, S. (1998). Tense over time: The longitudinal course of tense acquisition in children with specific language impairment. *Journal of Speech and Hearing Research, 41*, 1412-1431.

Rice, M. L., Wexler, K., & Redmond, S. M. (1999). Grammaticality judgements of an Extended Optional Infinitive grammar: Evidence from English-speaking children with specific language impairment. *Journal of Speech, Language, and Hearing Research, 42*(4), 943-961.

Roberts, J., Rescorla, L., & Borneman, A. (1994). *Morphosyntactic characteristics of early language errors: An examination of specific expressive language delay.* Paper presented at the Symposium on Research in Child Language Disorders, Madison, Wisconsin.

Robinson, R. (1987). The causes of language disorder: Introduction and overview, *Proceedings of the First International Symposium on Specific Speech and Language Disorders in Children* (pp. 1-19). London: Association for All Speech Impaired Children.

Rom, A., & Leonard, L. B. (1990). Interpreting deficits in grammatical morphology in specifically language-impaired children: Preliminary evidence from Hebrew. *Clinical Linguistics and Phonetics, 4*, 93-105.

Romani, A., Conte, S., Callieco, R., Bergamaschi, R., Versino, M., Lanzi, G., Zambrino, C.-A., & Cosi, V. (2001). Visual evoked potential abnormalities in dyslexic children. *Functional Neurology: New Trends in Adaptive and Behavioral Disorders, 16*(3), 219-229.

Rosen, S., & Manganari, E. (2001). Is there a relationship between speech and nonspeech auditory processing in children with dyslexia? *Journal of Speech, Language, and Hearing Research, 44*(4), 720-736.

Sachs, J. (1983). Talking about the there and then: The emergence of displaced reference in parent-child discourse. In K. E. Nelson (Ed.), *Children's language, Vol. 4*. Hillsdale, NJ: Lawrence Erlbaum Associates.

Scarborough, H. S. (1990). Very early language deficits in dyslexic children. *Child Development, 61*(1728-1743).

Schiller, P. H., Logothetis, N. K., & Charles, E. R. (1990). Role of colour-opponent and broad band channels in vision. *Visual Neuroscience, 5*, 321-346.

Schreiner, C. E., & Langner, G. (1988). Periodicity coding in the inferior colliculus of the cat II:

Topographical organization. *Journal of Neurophysiology, 60,* 1823-1840.
Scientific Learning Corporation. (1997). Fast ForWord™ (version 1.5). Berkeley, CA: Author.
Sek, A. (1994). Modulation detection thresholds and critical modulation frequency based on random amplitude and frequency changes. *Journal of the Acoustical Society of Japan (E), 15,* 67-75.
Semel, E., Wiig, E., & Secord, W. (1987). Clinical Evaluation of Language Fundamentals - Revised. San Antonio, TX: Psychological Corporation.
Shah, A., & Frith, U. (1983). An islet of ability in autistic children: A research note. *Journal of Child Psychology and Psychiatry, 24,* 613-620.
Shankweiler, D., Crain, S., Gorrell, P., & Tuller, B. (1989). Reception of language in Broca's aphasia. *Language and Cognitive Processes, 4*(1), 1-33.
Share, D. L., Jorm, A. F., MacLean, R., & Matthews, R. (2002). Temporal processing and reading disability. *Reading and Writing: An Interdisciplinary Journal, 15*(1-2), 151-178.
Sininger, Y., Klatsky, R., & Kirchner, D. (1989). Memory-scanning speed in language-disordered children. *Journal of Speech and Hearing Research, 32,* 289-297.
Skottun, B. C. (2000). The magnocellular deficit theory of dyslexia: the evidence from contrast sensitivity. *Vision Research, 40*(1), 111-127.
Skottun, B. C., & Parke, L. A. (1999). The possible relationship between visual deficits and dyslexia: Examination of a critical assumption. *Journal of Learning Disabilities, 32*(1), 2-5.
Slaghuis, W., & Lovegrove, W. J. (1984). Flicker masking of spatial frequency dependent visible persistence and specific reading disability. *Perception, 13,* 527-534.
Slaghuis, W., & Lovegrove, W. J. (1985). Spatial-frequency-dependent visible persistence and specific reading disability. *Brain and Cognition, 4*(2), 219-240.
Snow, D., & Swisher, L. (1996). Neurobehavioural analogies between syndromes of acquired and developmental language impairment: hypotheses for research. *Aphasiology, 10*(5), 453-468.
Snowling, M., Bishop, D. V. M., & Stothard, S. E. (2000). Is preschool language impairment a risk factor for dyslexia in adolescence? *Journal of Child Psychology and Psychiatry, 41*(5), 587-600.
Snowling, M., Chiat, S., & Hulme, C. (1991). Words, nonwords, and phonological processes: Some comments on Gathercole, Willis, Emslie, and Baddeley. *Applied Psycholinguistics, 12*(3), 369-373.
Snowling, M., Stothard, S., & Mclean, J. (1996). The Graded Nonword Reading Test. Bury St. Edmunds, U. K.: Thames Valley Test Company.
Snowling, M. J. (2000). *Dyslexia* (2 ed.). Oxford: Blackwell Publishers.
Snowling, M. J., Adams, J. W., Bishop, D. V. M., & Stothard, S. E. (2001). Education attainments of school leavers with a preschool history of speech-language impairments. *International Journal of Language and Communication Disorders, 36*(2), 173-183.
Spencer, J., O'Brien, J., Riggs, K., Braddick, O., Atkinson, J., & Wattam-Bell, J. (2000). Motion processing in autism: evidence for a dorsal stream deficiency. *NeuroReport, 11*(12), 2765-2767.
Stanovich, K. E. (1986). Cognitive processes and the reading problems of learning-disabled children: Evaluating the assumption of specificity. In J. Torgesen & B. Wong (Eds.), *Psychological and educational perspectives on learning disabilities* (pp. 87-131). New York: Academic Press.
Stanovich, K. E. (1988). Explaining the differences between the dyslexic and the garden-variety poor reader: The phonological-core variable-diffrence model. *Journal of Learning Disabilities, 21,* 590-604.
Stark, R. E., & Montgomery, J. W. (1995). Sentence processing in language-impaired children under conditions of filtering and time compression. *Applied Psycholinguistics, 16*(2), 137-154.
Stefanatos, G. A. (1993). Frequency modulation analysis in children with Landau-Kleffner Syndrome. In P. Tallal & A. M. Galaburda & R. R. Llinas & C. von Euler (Eds.), *Temporal Information Processing in the Nervous System: Special Reference to Dyslexia and Dysphasia* (Vol. 682, pp. 412-414). New York: A & PCP.
Stefanatos, G. A., Green, G. G. R., & Ratcliff, G. G. (1989). Neurophysiological evidence of auditory channel anomalies in developmental dysphasia. *Archives of Neurology, 46,* 871-875.
Stein, J., & Walsh, V. (1997). To see but not to read; the magnocellular theory of dyslexia. *Trends in Neurosciences, 20*(4), 147-152.
Stoodley, C. J., Talcott, J. B., Carter, E. L., Witton, C., & Stein, J. F. (2000). Selective deficits of vibrotactile sensitivity in dyslexic readers. *Neuroscience Letters, 295*(1-2), 13-16.
Stothard, S. E., Snowling, M. J., Bishop, D. V. M., Chipchase, B. B., & Kaplan, C. A. (1998). Language-

impaired preschoolers: A follow-up into adolescence. *Journal of Speech, Language and Hearing Research, 41*(April), 407-418.
Studdert-Kennedy, M., & Mody, M. (1995). Auditory temporal perception deficits in the reading-impaired: A critical review of the evidence. *Psychonomic Bulletin & Review, 2*(4), 508-514.
Sussman, J. E. (1993). Perception of formant transition cues to place of articulation in children with language impairments. *Journal of Speech and Hearing Research, 36*(6), 1286-1299.
Talcott, J. B., Hansen, P. C., Assoku, E. L., & Stein, J. F. (2000). Visual motion sensitivity in dyslexia: evidence for temporal and energy integration deficits. *Neuropsychologia, 38*(7), 935-943.
Talcott, J. B., Hansen, P. C., Willis-Owen, C., McKinnell, I. W., Richardson, A. J., & Stein, J. F. (1998). Visual magnocellular impairment in adult developmental dyslexics. *Neuro-ophthalmology, 20*(4), 187-201.
Talcott, J. B., Witton, C., McLean, M. F., Hansen, P. C., Rees, A., Green, G. G. R., & Stein, J. F. (2000). Dynamic sensory sensitivity and children's word decoding skills. *Proceedings of the National Academy of Sciences of the United States of America, 97*(6), 2952-2957.
Tallal, P. (1980). Auditory temporal perception, phonics, and reading disabilities in children. *Brain and Language, 9*, 182-198.
Tallal, P., Allard, L., Miller, S., & Curtiss, S. (1997). Academic outcomes of language impaired children. In C. Hulme & M. Snowling (Eds.), *Dyslexia: Biology, Cognition & Intervention* (pp. 167-181). London: Whurr Publishers Ltd.
Tallal, P., Miller, S., & Fitch, R. H. (1993). Neurobiological basis of speech: A case for the preeminence of temporal processing. In P. Tallal & A. M. Galaburda & R. R. Llinas & C. von Euler (Eds.), *Temporal Information Processing in the Nervous System: Special Reference to Dyslexia and Dysphasia* (Vol. 682, pp. 27-47). New York: A & PCP.
Tallal, P., Miller, S. L., Bedi, G., Byma, G., Wang, X., Nagarajan, S. S., Schreiner, C., Jenkins, W. M., & Merzenich, M. M. (1996). Language comprehension in language-learning impaired children improved wtih acoustically modified speech. *Science, 271*(5 January), 81-84.
Tallal, P., & Piercy, M. (1973a). Defects of non-verbal auditory perception in children with developmental aphasia. *Nature, 241*(February 16), 468-469.
Tallal, P., & Piercy, M. (1973b). Developmental aphasia: Impaired rate of nonverbal processing as a function of sensory modality. *Neuropsychologia, 11*, 389-398.
Tallal, P., & Piercy, M. (1974). Developmental aphasia: Rate of auditory processing and selective impairment of consonant perception. *Neuropsychologia, 12*, 83-93.
Tallal, P., & Piercy, M. (1975). Developmental aphasia: The perception of brief vowels and extended stop consonants. *Neuropsychologia, 13*, 69-74.
Tallal, P., & Stark, R. (1981). Speech acoustic-cue discrimination abilities of normally developing and language-impaired children. *Journal of the Acoustical Society of America, 69*, 568-574.
Tallal, P., Stark, R., & Curtiss, B. (1976). Relation between speech perception and speech production in children with developmental dysphasia. *Brain and Language, 3*, 305-317.
Tallal, P., Stark, R., Kallman, C., & Mellits, D. (1981). A re-examination of some nonverbal perceptual abilities of language-impaired and normal children as a function of age and sensory modality. *Journal of Speech and Hearing Research, 24*(351-357).
Taylor, M. M., & Creelman, C. D. (1967). PEST: Efficient estimates on probability functions. *Journal of the Acoustical Society of America, 41*, 782-787.
Tomblin, J. B. (1996). Genetic and environmental contributions to the risk for specific language impairment. In M. L. Rice (Ed.), *Toward a genetics of language* (pp. 191-210). Mahwah, NJ: Lawrence Erlbaum.
Tomblin, J. B., Abbas, P. J., Records, N. L., & Brenneman, L. M. (1995). Auditory evoked responses to frequency-modulated tones in children with specific language impairment. *Journal of Speech and Hearing Research, 38*(April), 387-392.
Trehub, S. E., Schneider, B. A., & Bull, D. (1981). Effect of reinforcement on infants' performance in an auditory detection task. *Developmental Psychology, 17*, 872-877.
Trussell, L. O. (1997). Cellular mechanisms for preservation of timing in central auditory pathways. *Current Opinion in Neurobiology, 7*(4), 487-492.
Tyler, A. (1992). *Spoken language comprehension: An experimental approach to disordered and normal processing*. Cambridge, MA: The MIT Press.
Tyler, L. K., Randall, B., & Marslen-Wilson, W. D. (2002). Phonology and neuropsychology of the English

past tense. *Neuropsychologia, 40*(8), 1154-1166.
Ullman, M., & Gopnik, M. (1994). Past tense production: Regular, irregular and nonsense verbs. *McGill Working Papers in Linguistics, 10*, 81-118.
Ullman, M., & Gopnik, M. (1999). Inflectional morphology in a family with inherited specific language impairment. *Applied Psycholinguistics, 20*, 51-117.
van Daal, J. (2002). Personal communication. Meeting of the Oxford Study of Children's Communication Impairments.
van der Lely, H. K. J. (1994). Canonical linking rules forward versus reverse linking in normally developing and specifically language-impaired children. *Cognition, 51*, 29-72.
van der Lely, H. K. J. (1996). Specifically language impaired and normally developing children: Verbal passive vs. adjectival passive sentence interpretation. *Lingua, 98*, 243-272.
van der Lely, H. K. J. (1997). Narrative discourse in grammatical specific language impaired children: a modular language deficit? *Journal of Child Language, 24*, 221-256.
van der Lely, H. K. J., & Harris, M. (1990). Comprehension of reversible sentences in specifically language impaired children. *Journal of Speech and Hearing Research, 55*, 101-117.
van der Lely, H. K. J., Rosen, S., & McClelland, A. (1998). Evidence for a grammar-specific deficit in children. *Current Biology, 8*, 1253-1258.
van der Lely, H. K. J., & Stollwerck, L. (1997). Binding theory and grammatical specific language impairment in children. *Cognition, 62*, 245-290.
van der Lely, H. K. J., & Ullman, M. (1995). *The computation and representation of past-tense morphology in specifically language impaired and normally developing children.* Paper presented at the Boston University Conference on Language Development, Boston.
Vargha-Khadem, F., Watkins, K., Alcock, K., Fletcher, P., & Passingham, R. (1995). Praxic and nonverbal cognitive deficits in a large family with a genetically transmitted speech and language disorder. *Proceedings of the National Academy of Sciences, 92*, 930-933.
Vellutino, F. R., & Scanlon, D. M. (1987). Phonological coding, phonological awareness, and reading ability: Evidence from a longitudinal and experimental study. *Merrill-Palmer Quarterly, 33*, 321-363.
Vidyasagar, T. R. (1998). Gating of neuronal responses in macaque primary visual cortex by an attentional spotlight. *NeuroReport, 9*(9), 1947-1952.
Vidyasagar, T. R., & Pammer, K. (1999). Impaired visual search in dyslexia relates to the role of the magnocellular pathway in attention. *NeuroReport, 10*, 1283-1287.
Warren-Leubecker, A. (1982). *Sex differences in speech to children.* Unpublished doctoral dissertation. Georgia Institute of Technology.
Wells, C. G. (1981). *Learning through interaction: The study of language development.* Cambridge: Cambridge University Press.
Werner, L. A. (1992). Interpreting developmental psychoacoustics. In L. A. Werner & E. W. Rubel (Eds.), *Developmental Psychoacoustics* (pp. 47-88). Washington, D.C.: American Psychological Association.
Werner, L. A., & Feeney, M. P. (1990). *Pure-tone sensitivity of 2- to 4-week-old infants assessed with auditory reinforcement.* Paper presented at the International Conference for Infant Studies, Montreal.
Wexler, K. (1994). Optional infinitives. In D. Lightfoot & N. Hornstein (Eds.), *Verb movement* (pp. 313-350). New York, NY: Cambridge University Press.
Wexler, K. (1996). The development of inflection in a biologically based theory of language acquisition. In M. L. Rice (Ed.), *Towards a genetics of language* (pp. 113-144). Mahwah, NJ: Lawrence Erlbaum.
Wexler, K., Schuetze, C. T., & Rice, M. L. (1998). Subject case in children with SLI and unaffected controls: Evidence for the Agr/Tns Omission Model. *Language Acquisition: A Journal of Developmental Linguistics, 7*(2-4), 317-344.
Whitfield, I. C., & Evans, E. F. (1965). Responses of auditory cortical neurons to stimuli of changing frequency. *Journal of Neurophysiology, 28*, 655-672.
Wightman, F., & Allen, P. (1992). Individual differences in auditory capability among preschool children. In L. A. Werner & E. W. Rubel (Eds.), *Developmental Psychoacoustics* (pp. 113-133). Washington, D.C.: American Psychological Association.
Williams, D., Stott, C. M., Goodyer, I. M., & Sahakian, B. J. (2000). Specific language impairment with or

without hyperactivity: neuropsychological evidence for frontostriatal dysfunction. *Developmental Medicine and Child Neurology, 42*(6), 368-375.

Windsor, J., & Hwang, M. (1999). Testing the generalized processing hypothesis in specific language impairment. *Journal of Speech, Language, and Hearing Research, 42*, 1205-1218.

Witton, C., Stein, J. F., Stoodley, C. J., Rosner, B. S., & Talcott, J. B. (2002). Separate influences of acoustic AM and FM sensitivity on the phonological decoding skills of impaired and normal readers. *Journal of Cognitive Neuroscience, 14*, 866-874.

Witton, C., Talcott, J. B., Hansen, P. C., Richardson, A. J., Griffiths, T. D., Rees, A., Stein, J. F., & Green, G. G. R. (1998). Sensitivity to dynamic auditory and visual stimuli predicts nonword reading ability in both dyslexic and normal readers. *Current Biology, 8*, 791-797.

Wolfus, B., Moscovitch, M., & Kinsbourne, M. (1980). Subgroups of developmental language impairment. *Brain and Language, 10*, 152-171.

Wright, B. A., Lombardino, L. J., King, W. M., Puranik, C. S., Leonard, C. M., & Merzenich, M. M. (1997). Deficits in auditory temporal and spectral resolution in language-impaired children. *Nature, 387*(8 May), 176-178.

Wulfeck, B., & Bates, E. (1991). Differential sensitivity to errors of agreement and word order in Broca's aphasia. *Journal of Cognitive Neuroscience, 3*(3), 258-272.

Wulfeck, B., & Bates, E. (1995). *Grammatical sensitivity in children with language impairment* (Technical Report CND-9512): Center for Research in Language, University of California at San Diego.

Wulfeck, B. B. (1993). A reaction time study of grammaticality judgements in children. *Journal of Speech and Hearing Research, 36*, 1208-1215.

Zihl, J., von Cramon, D., & Mai, N. (1983). Selective disturbance of movement vision after bilateral brain damage. *Brain, 106*, 313-340.

Zurif, E. B., & Grodzinsky, Y. (1983). Sensitivity to grammatical structure in agrammatic aphasics: A reply to Linebarger, Schwartz, and Saffran. *Cognition, 15*, 207-221.

Zwicker, E. (1952). Die grenzen der horbarkeit der amplitudenmodulation und der frequenzmodulation eines tones. *Acustica, 2*, 125-133.