On-line processing of wh-questions in children with G-SLI and typically developing children

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Abstract

Background: The computational grammatical complexity (CGC) hypothesis claims that children with G(rammatical)-specific language impairment (SLI) have a domain-specific deficit in the computational system affecting syntactic dependencies involving 'movement'. One type of such syntactic dependencies is filler-gap dependencies. In contrast, the Generalized Slowing Hypothesis claims that SLI children have a domain-general deficit affecting processing speed and capacity.
Aims: To test contrasting accounts of SLI we investigate processing of syntactic (filler-gap) dependencies in wh-questions.
Methods & Procedures: Fourteen 10;2–17;2 G-SLI children, 14 age-matched and 17 vocabulary-matched controls were studied using the cross-modal picture-priming paradigm.
Outcomes & Results: G-SLI children's processing speed was significantly slower than the age controls, but not younger vocabulary controls. The G-SLI children and vocabulary controls did not differ on memory span. However, the typically developing and G-SLI children showed a qualitatively different processing pattern. The age and vocabulary controls showed priming at the gap, indicating that they process wh-questions through syntactic filler-gap dependencies. In contrast, G-SLI children showed priming only at the verb.
Conclusions: The findings indicate that G-SLI children fail to establish reliably a syntactic filler-gap dependency and instead interpret wh-questions via lexical–thematic information. These data challenge the Generalized Slowing Hypothesis account, but support the CGC hypothesis, according to which G-SLI children have a particular deficit in the computational system affecting syntactic dependencies involving 'movement'. As effective remediation often depends on aetiological insight, the discovery of the nature of the syntactic deficit, along side a possible compensatory use of semantics to facilitate sentence processing, can

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be used to direct therapy. However, the therapeutic strategy to be used, and whether such similar strengths and weaknesses within the language system are found in other SLI subgroups are empirical issues that warrant further research.

Keywords: SLI, on-line processing, Wh-Questions.

What this paper adds
Our understanding of underlying processes that children with specific language impairment use when processing sentences is still little understood. This study uses an on-line methodology to investigate processing of wh-questions in Grammatical - (G) SLI children. We discovered that G-SLI children do not establish syntactic dependencies involving movement (filler-gap dependencies) and instead interpret wh-questions via lexical-thematic information. These data support the Computational Grammatical Complexity hypothesis and add to our understanding of how G-SLI children process questions. The results provide insight into the underlying nature of G-SLI– their weaknesses and strengths and thereby should assist the clinicians in directing remediation.

Introduction

Specific language impairment (SLI) is a "heterogeneous developmental language disorder in the absence of hearing impairment, frank neurological impairment or psycho-emotional disturbance (Bishop 1997, Leonard 1998). There is a considerable controversy surrounding the nature of SLI. This revolves around whether SLI reflects a domain-general deficit causing an input-phonological and/or processing deficit (Kail 1994, Joanisse and Seidenberg 1998, Leonard 1998) or a domain-specific deficit in grammar causing specific aspects of the grammatical system to be impaired (Clahsen 1989, Gopnik 1990, Rice and Wexler 1996, van der Lely 1998). One reason for this controversy is that SLI is a heterogeneous disorder, and it is likely that there is more than one cause, as exemplified by phenotypic and genotypic data (SLI Consortium 2002, 2004, Bishop 2003, van der Lely 2005). A second reason for the controversy is that many findings are compatible with both types of accounts (van der Lely 2005). To evaluate these accounts and contribute to the debate, an on-line cross-modal picture priming experiment was used and a subgroup of children with SLI, G(rammatical)-SLI children, was investigated.

Heterogeneity in SLI and the G-SLI subgroup

The heterogeneity of SLI groups has resulted from it being studied, historically, from a clinical perspective and from being defined by exclusion. Recent integration of theoretical approaches from a linguistics, psycholinguistics, neuroscience, molecular genetics and evolutionary biology perspective is bringing finer-grained criteria and tests that are better motivated psycholinguistically for identifying SLI (Enard *et al.* 2002, Marcus and Fisher 2003, SLI Consortium 2004). These developments are enabling us to identify subgroups within the SLI population and are changing one's

understanding of the disorder. It is now generally accepted that SLI is unlikely to be one but many disorders. Varied phenotypes have been documented over many years: some children exhibit deficits throughout the language system (Bishop 1997), whereas others exhibit primary deficits in vocabulary: Lexical (L)-SLI, or children with word-finding difficulties (Dockrell *et al.* 2001), or pragmatics (P)-SLI (Bishop 2000, Botting and Conti-Ramsden 2003). Furthermore, some children's core deficits are restricted to grammar (syntax, morphology, phonology), e.g. grammatical (G)-SLI (van der Lely 1998, 2005), or even components within grammar–syntax (Rice *et al.* 2000, Friedmann and Novogrodsky 2004), morphology (Marshall and van der Lely 2006), and phonology (Gathercole and Baddeley 1990). Furthermore, some children with SLI show additional deficits in auditory, cognitive or even motor abilities (Bishop 1997, Leonard 1998, Tallal 2002, Bishop and McArthur 2005), suggesting that some forms of the disorder, and by implication some mechanisms underlying some aspects of the language systems, are not so specific as once thought, albeit that as yet no direct link has been established between any of these non-linguistic deficits and their language deficits (van der Lely *et al.* 2004, van der Lely 2005). Our knowledge has been enriched by the recent genotypic findings which suggest that different genetic variants underlie different phenotypes (Newbury and Monaco 2002). For example, loci on chromosomes 16q and 19q have been linked with different types of impairment — a deficit in phonological short-term memory and a deficit in expressive language respectively (SLI Consortium 2002). It is only by identifying pertinent SLI phenotypes that one can illuminate the precise nature of the different variants of SLI.

In this paper, focus is on the G-SLI subgroup. G-SLI children are hypothesized to be a comparatively homogeneous subgroup of the SLI population, characterized by a persistent and relatively pure grammatical impairment in at least three components of the grammatical system: syntax, morphology and for most phonology too (van der Lely 2005). Extensive testing has not revealed any pragmatic or non-verbal deficits or consistent auditory processing impairments (van der Lely *et al.* 2004, van der Lely 2005). In this paper, we focus on their syntactic deficit. The children are all over 9;0 (years;months) and make a substantial number of errors (typically well over 20%) across a broad range of morpho-syntactic phenomena at an age when such errors are rarely found in the normal population after 5 years, such as in tense-marking, assigning theta roles in reversible sentences, assigning co-reference to pronouns and reflexives, and producing wh-questions (for reviews, see van der Lely 1998, 2005). The extent to which this subgroup and the nature of their impairment overlap with other SLI subgroups is an empirical issue. This paper contributes to this issues by further characterizing the G-SLI subgroup.

Domain-general versus domain-specific accounts of SLI

There are two main theoretical frameworks which underlie hypotheses about SLI. On the one hand, domain-general perspectives consider that the SLI deficit is not specific to grammar or even language, but it is caused by a non-linguistic processing deficit, e.g. reduced speed of processing and limitations in processing capacity (Kail 1994, Joanisse and Seidenberg 1998, Leonard 1998). According to Kail's (1995) Generalized Slowing Hypothesis, children with SLI are slower in information processing in both linguistic and non-linguistic tasks. In this model, speed of processing is employed as a metric of processing capacity. The underlying idea is

that speed determines the amount of work that can be accomplished in a given unit of time. Within this hypothesis, any given task is likely to involve several processes. For example, picture naming would involve: (1) recognition of the picture, (2) retrieval of the name of the picture, (3) formulation of the name, and (4) production of the name (Miller *et al.* 2001). Reaction times for typically developing children are influenced by the time required for each one of these processes. According to Kail, children with SLI are slower than typically developing children in each one of these processes by a common factor, and thus, SLI children's reaction times should differ from those of typically developing children to the same degree across tasks that require the same number of processes (Miller *et al.* 2001). Indeed, several studies revealed that children with SLI have slower reaction times compared with age-matched controls across a wide range of tasks, involving both linguistic and non-linguistic activities (Johnston and Weismer 1983, Stark and Montgomery 1995, Miller *et al.* 2001), and thus, provide evidence for the Generalized Slowing Hypothesis. As far as we are aware, this hypothesis has not been applied to subgroups of children with SLI to more precisely define which type of SLI could be explained by this model.

On the other hand, domain-specific perspectives claim that SLI results from a deficit in the grammatical system itself (Clahsen 1989, Gopnik 1990, Gopnik and Crago 1991, Rice 1996, Rice and Wexler 1996, van der Lely 1998). For example, the Missing Feature Account (Gopnik 1990) claims that children lack grammatical features, the Agreement Deficit Account (Clahsen 1989) argues that SLI children have difficulties in establishing agreement relations and the Agreement/Tense Omission Model (Wexler 1999), which is a more recent development of the Extended Optional Infinitive (EOI) model, explains SLI children's errors through the Unique Checking Constraint.

To account for G-SLI, van der Lely and colleagues have developed the Deficit in Computational Grammatical Complexity (CGC) hypothesis (van der Lely 2004, 2005, Marshall and van der Lely 2006) a development of the Representational Deficit for Dependent Relations (RDDR) account (van der Lely 1998). The CGC Hypothesis claims that the core deficit in some but not all forms of SLI is in the representation and/or mechanisms underlying the construction of hierarchical grammatical structures.[1] For G-SLI children their grammar is characterized by Grammatical Structural Economy in syntax, morphology and for most phonology too. Thus, the least complex structure will surface. Within the syntactic component, the core deficit is in computing syntactic dependencies between constituents. Within Chomsky's Minimalist Program (Chomsky 1995), this can be implemented as optionality of the operation *Move*, which is not 'automatic' and 'compulsory'. Further, complexity is defined as the number of movement operations, thus subject questions are predicted to be less problematic than object questions because the former has one less movement operation (van der Lely and Battell 2003). van der Lely and colleagues demonstrated that the CGC hypothesis accounts for a wide range of phenomena in English G-SLI children. More recently, several studies have tested this hypothesis cross-linguistically (e.g. Stavrakaki 2001, Friedmann and Novogrodsky 2004) using off-line techniques.

To date, there are relatively few studies investigating how children with SLI process sentences in real time (e.g. Montgomery *et al.* 1990, Montgomery and Leonard 1998, Montgomery 2000). To test how the CGC and Kail's Generalized Slowing Hypothesis can account for on-line sentence processing in G-SLI children,

we studied how G-SLI children process wh-questions in real time, comparing their performance to the performance of typically developing children of similar age and younger vocabulary-matched controls.

The next section provides a brief outline of the relevant theoretical issues concerning wh-movement and previous findings of the performance of wh-questions in children with G-SLI.

Wh-questions, movement and G-SLI

Wh-questions in English involve two types of movement: movement of the wh-word to the beginning of the sentence (operator-movement; hereafter wh-movement) and movement of the auxiliary from I-to-C (Head-to-Head movement, hereafter head movement), as illustrated in example (1) below:

(1) $[_{CP}\textit{What}_i [_{C}\text{did}_j][_{IP}\text{Bart} [_{I}t_j][_{VP} [_{V}\text{kick}] t_i[_{PP} \text{at the farm}]]]]$
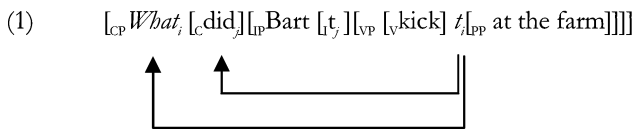
The CGC hypothesis predicts that G-SLI children should have problems with both types of movement and those structures requiring more movement operations (such as object questions, embedded questions or relative clauses) will be more problematic than those requiring fewer (such as subject questions). van der Lely and Battell (2003) investigated the production of wh-questions, and showed that G-SLI children were significantly impaired in producing wh-questions and made errors, such as (2)–(4) below:

(2)   What cat Mrs White stroked?
(3)   What did Mrs Peacock like jewellery?
(4)   Who Mrs Peacock saw somebody?

Example (2) shows a lack of *do-support*, an error related to I-to-C movement; example (3) illustrates a pied-piping/gap-filling error; the DP *the jewellery* appears at the position of the gap (target question: *What jewellery did Mrs Peacock like?*), and example (4) demonstrates a combination of both error types. In addition, consistent with predictions, children with G-SLI made significantly more errors in object as opposed to subject questions with an error rate of 17.8% for subject and 27.8% for object questions, whereas the error rate of TD children matched on grammar was 1.8 and 8.8% and TD children matched on vocabulary showed 0% errors in both question types.

Similarly to the CGC, processing accounts on SLI attributing the impairment to processing limitations also predict that SLI children should have difficulties with wh-questions (Deevy and Leonard 2004), but for different reasons. The decisive factor here is not a specific impairment in grammatical processing or representation (van der Lely 1999a), but a general reduction in processing capacity. Therefore, any increase in cognitive load would be predicted to reduce performance. Thus, increased distance between the moved wh-word (filler) and the position it has moved from (gap/trace) should impact on the performance of children with SLI to a greater degree than TD children due to processing limitations. Deevy and Leonard tested this hypothesis in an off-line comprehension task by manipulating the distance between the filler and the gap — the distance is larger in object as opposed

to subject wh-questions and Deevy and Leonard also used short and long wh-questions. Children with SLI and vocabulary controls performed equally well in short subject and object wh-questions. The two groups differed significantly from each other only in long object wh-questions — the sentence type with the longer distance between the filler and the gap. Moreover, SLI children performed poorer in long object wh-questions as opposed to long subject wh-questions. Based on this data, Deevy and Leonard argued that the difficulties experienced by children with SLI relate to limitations in their linguistic processing abilities.

The present paper addresses this issue by exploring G-SLI children's processing of wh-questions using on-line methodology. On-line experiments alongside off-line tasks enable one to examine not only how fast and accurate children process sentences but also whether they process wh-questions in the same way as TD children do.

Sentence processing of filler-gap dependencies in adults and children

A considerable amount of research in sentence processing has revolved around how adults process sentences that involve movement and whether the parser establishes a syntactic dependency between the moved constituent (filler) and its trace (gap), a so-called filler-gap dependency (Swinney *et al.* 1988, Nicol and Swinney 1989, Nicol 1993). For example, in sentences, such as (5) below, Swinney *et al.* (1988) found a priming effect of the word *boy* at the position of the trace. This suggests that the filler (*boy*) is mentally reactivated at the position of the trace (t_i) and provides evidence that the parser establishes a syntactic dependency between the filler and the gap:

(5)   The policeman saw the *boy$_i$* that the crowd at the party accused t_i of the crime.

Two hypotheses have been articulated to explain these results, the Trace Reactivation Hypothesis (Swinney *et al.* 1988) and the Direct Association Hypothesis (Pickering and Barry 1991). According to the Trace Reactivation Hypothesis, the parser holds the filler temporarily in short term memory. Then, when the parser identifies a trace/gap, it retrieves the filler from short-term memory and sets up a filler-gap dependency by reconstructing the grammatical and semantic features of the filler at the position of the gap. In contrast to this hypothesis, the Direct Association Hypothesis does not make use of traces. Within this hypothesis, the filler is integrated as quickly as possible even before the position of the gap. For example, in (5) above, the parser would form a dependency between the filler and its subcategorizer — the verb. The results of Swinney *et al.* could not distinguish between the two hypotheses because in their material, the trace was adjacent to the verb, and so the effect observed in this position could be either an effect of the trace or of the verb. Moreover, Nicol (1993) found a priming effect on both the trace and the verb (but cf. Clahsen and Featherston 1999, Nakano *et al.* 2002, who provided unambiguous data for reactivation of the trace in German and Japanese adults). These two hypotheses are relevant for the present study, as processing at both the position of the trace and the position of the verb was tested.

Research into children's sentence processing has investigated whether children process syntactic information similarly to adults. For example, Tyler and Marslen-Wilson (1981) showed that 5–10-year-old children behave like adults when monitoring words in normal, semantically and syntactically anomalous sentences. Further, McKee *et al.* (1993), using the cross-modal picture priming methodology,

found that children as young as 4, just like adults (Nicol 1988), obey binding constraints. Making use of the same methodology, Roberts *et al.* (In press) found that 6–7-year-old children are capable of establishing filler-gap dependencies in object relative clauses. Finally, Friederici and Hahne (2000) using Event Related Potentials (ERPs) revealed that, like adults, 7- and 8-year-old children on encountering syntactically anomalous sentences showed an early left anterior negativity (ELAN), which is associated with first-pass parsing processes. However, there was a difference in the latency of this effect between 7-year-old children on the one hand and 8-year-old children and adults on the other hand. In adults and 8-year-old children, the ELAN started at 150 ms and extended up to 350 ms, whereas in 7-year-old children the ELAN started at 400 ms and extended beyond 1000 ms. According the Friederici and Hahne, this pattern shows that 7- and 8-year-old children base their first-pass parsing processes on brain systems similar to adults. However, 7 year olds' first-pass parsing routines are much slower.

Sentence processing in children with SLI

Studies in sentence processing by children with SLI have focused on two issues: (1) speed of processing, and (2) processing patterns.

Montgomery *et al.* (1990), Stark and Montgomery (1995), and Montgomery (2000, 2002) used the word-monitoring paradigm to investigate speed of processing in children with SLI. These studies showed that children with SLI process spoken language slower than TD children matched on age or language abilities. However, the SLI children although slower, did not differ qualitatively in the processing pattern from TD children. All groups' reaction times decreased as words occurred later in the sentence. This finding concurs with that found in investigations of sentence processing in TD children (Tyler and Marslen-Wilson 1981).

However, some on-line investigations have revealed a qualitatively different processing pattern between children with SLI and TD children. Using a word monitoring task, in which children had to monitor words following inflected verbs with low perceptual salience (third-person-singular *-s* and past tense *-ed*) versus high perceptual salience (present-progressive *-ing*), Montgomery and Leonard (1998) found that TD children showed longer reaction times when both types of inflectional morphemes were missing. In contrast, children with SLI showed this effect only in the condition involving words with high perceptual salience. Montgomery and Leonard argued that this provides evidence in favour of the Surface Account, a domain-general hypothesis. To evaluate domain general versus domain specific accounts further, we studied processing of syntactic dependencies in wh-questions.

Predictions for the processing of wh-questions in G-SLI children

Caveat

Both domain-general and domain-specific hypotheses predict that children with SLI will show differences in sentence processing (Montgomery and Leonard 1998, van der Lely 2005). Experimental tasks do not directly tap representations, but the outcome of processing. Therefore, with some paradigms and designs, it is very difficult to distinguish effects of general processing versus specific grammatical processing deficits. Impaired processing of sentences or perception of sound sequences per se

cannot be taken as evidence for either position, as processing and knowledge are not independent: an SLI child's inability to process a particular sound-sequence might equally be due to impaired representations of hierarchical syntactic dependencies, or to some lower-level processing or memory deficit, that feeds bad input to a potentially good grammatical analyser (van der Lely 2005). To address this issue, the aim is to make finer grained predictions in order *a priori* to distinguish the theories.

The Generalized Slowing Hypothesis (Kail 1994) first predicts that G-SLI children should show longer reaction times than TD children matched on age. This is based on the central claim of this account that SLI children are slow information processors. Second, if G-SLI children have difficulties performing a dual-task because dual-tasks require large processing resources, one might expect their processing speed to be similar to younger control children matched on vocabulary. Further, if processing speed affects priming, then the G-SLI children and the younger vocabulary controls should show a similar priming effect, and this could differ from the priming effect of age controls. Finally, processing difficulty in G-SLI and vocabulary controls could be reflected in reduced or lack of priming effects if these are measured immediately after the end of a word. This is based on the idea that slow processors will need more time to process the input, and therefore, a priming effect will not show up at the offset of a word, but later in the sentence. In principle this should affect all possible priming effects. However, given that processing demands increase with the length of the sentence, priming effects later in the sentence should be more susceptible than priming effects relatively early in the sentence (Montgomery 1995, 2000).

The CGC hypothesis also predicts that children with G-SLI should process sentences slower than the age controls, but this is because they have impaired representations or specialized processing mechanisms underlying representations of syntactic dependencies involving movement. Therefore, in addition, the CGC hypothesis predicts that children with G-SLI will show a difference in the priming effect between the gap and the subcategorizing verb. If in children with G-SLI the operation *Move* is optional in a substantial number of occasions and wh-words are merged directly at the specifier of the Complementizer Phrase (CP) (van der Lely and Battell 2003), G-SLI children should show reduced or no reactivation at the position of the gap.[2] However, G-SLI children could show a priming effect at the subcategorizing verb (Direct Association Hypothesis; Pickering and Barry 1991): on encountering the verb they might reactivate the verb's arguments/theta roles. This requires semantic–lexical knowledge rather than a syntactic dependency involving movement.

Methods

Subjects

Three groups of subjects participated in this study. A group of G-SLI children, a group of TD children matched with the G-SLI children on age and non-verbal IQ (age controls) and a group of younger TD children matched with the G-SLI children on their single word vocabulary comprehension and on their memory span (language controls). The use of two control groups allows one to determine independently the effects of age and vocabulary (a general measure of language) on performance.

Grammatical SLI children

Fourteen G-SLI children and teenagers (five girls and nine boys) aged between 10;2 and 17;2 (years;months) participated in this study. All subjects met the criteria for G-SLI, as described in van der Lely (1998, 2005), that is all children had persistent problems with grammatical components of language (syntax, morphology and for most phonology too) in their production and comprehension as evinced through standardized and non-standardized tests, but showed normal non-verbal IQ (85 or above), articulatory motor abilities, speech intelligibility and social emotional behaviour.

First, all children were diagnosed by speech and language therapists as SLI — that is as having a significant language impairment but non-verbal IQ falling within the normal range. Any child reported by speech and language therapists or teaching staff as suffering from Pragmatic disorders or Pragmatic-SLI was excluded. Three standardized tests were initially used for the selection of the children with SLI; the Test of Reception of Grammar (TROG),[3] a test of sentence comprehension (Bishop 1989), and the British Picture Vocabulary Scale (BPVS-II), a single word vocabulary test (Dunn *et al*. 1997). Only children showing a significant language impairment on at least one test was included for further testing. The SLI children's non-verbal IQ was assessed on the Raven's progressive matrices (Raven 1990) and the subtest Block Design of the British Ability Scales (BAS-II) (Elliott 1996). Only children scoring at an IQ of 85 or above were included in the final group.

Second, tests were carried out which assess aspects of grammar that characterize the core deficit in G-SLI children, that is: the Grammatical Closure subtest from the Illinois Test of Psycholinguistic Abilities (ITPA), a test of production of morpho-syntax (Kirk *et al*. 1968), and two non-standardized tests — the Verb Agreement and Tense Test (VATT) (van der Lely 1999b) and the Test of Active and Passive Sentences (TAPS) (van der Lely 1996). Each G-SLI subject included in this study showed a significant impairment on the ITPA and made 20% or more errors on each of the non-standardized tests. Note TD children rarely make any errors on these tests after 6 years of age. Approximately 20% of those children who are referred as SLI over the age of 9 years who also have normal IQ meet these criteria (van der Lely and Stollwerck 1996).

The mean z-score for the selected G-SLI subgroup on TROG was -1.45 (equivalent age 7;7), whereas their mean z-score on BPVS II was -1.51 (equivalent age 9;1)[4] and on the ITPA was -3.51 (equivalent age 6;9). Their mean non-verbal IQ was 95.32 (range 85–127) as measured on Ravens matrices (Raven 1990) and the subtest Block Design of the British Ability Scales (BAS-II) (Elliott 1996).

Finally, G-SLI children's memory capacity was tested with a listening span task for children (Gaulin and Campbell 1994). This is an adaptation of Daneman and Carpenter's (1980) reading span task and involves listening to sets of one to six sentences, providing a truth-value judgement for each sentence, and then recalling the last word of each of the sentences at the end of each set. Table 1 summarizes the subjects' details and their scores in the standardized tests and in the memory span task, and Appendix A provides individual subject details for the G-SLI group.

Age-matched control group

A group of 14 TD children of similar age to the SLI children provided an age-matched (CA) control group. The children were randomly selected from schools in

Table 1.   Summary of the subjects' details for the G-SLI and control children

	G-SLI (*n*=14)		CA (*n*=14)		LA (*n*=17)	
	Mean	SD	Mean	SD	Mean	SD
Chronological age[b]	13;3	(24.79)	13;7	(31.63)	9;1	(4.7)
Age range	10;2–17;2		9;8–16;10		8;3–9;6	
TROG[a]	13.79	(3.21)	18.43	(1.22)	16.82	(1.42)
Z-score	−1.49	(0.64)	0.53	(1.13)	0.06	(0.74)
Equivalent age	7;7	(24.92)	c		9;9	(17.06)
BPVS-II	88.79	(19.47)	132.07	(25.28)	92	(12.87)
Z-score	−1.51	(0.92)	1.52	(1.76)	0.03	(0.77)
Equivalent age	9;1	(28.24)	14;5	(35.11)	9;4	(20.97)
BAS II/Ravens	95.32	(11.61)	101.86	(13.18)	93.13	(9.32)
Memory span	2.56	(0.61)	3.29	(0.99)	2.56	(0.53)

TROG[a], Test of Reception of Grammar; BPVS-II, British Picture Vocabulary Scale; BAS II, British Ability Scales.
[b]Mean=years; months, SD=months.
[c]Scores for equivalent age are not available for the scores of the subjects.

Central London and their language abilities were assessed using TROG and BPVS. Only children that fell within the normal range abilities were included in this study. In addition, Raven's Matrices was administered to make sure that their cognitive abilities were at a similar level to those of the G-SLI children, and the memory span task to ascertain their memory span level. The children in this group had a mean age of 13;7 (range 9;8–16;10), which did not differ significantly from those of the G-SLI children (t (26)=0.293, p=0.772). Their mean non-verbal IQ score was 101.86 (range 85–127) and also did not differ significantly from that of the G-SLI group (t (26)=1.392, p=0.176). Their memory span was significantly higher than the memory span of the G-SLI children (t (26)=3.205, p=0.004) and the language ability controls (t (29)=2.509, p=0.014) (Table 1).

Younger language ability control group

A group of seventeen typically developing children was selected as language ability (LA) control group. The children in this group had a mean age of 9;1 (range 8;3–9;6), and were significantly younger than the children with G-SLI (t (29)=−8.272, p<0.001). These children were assessed on both TROG and BPVS for matching purposes and to ensure that all children fell within the normal range of language abilities, and also on memory span. Their raw scores in TROG were significantly higher than those of the G-SLI group (t (29)=3.509, p=0.001). In contrast, their raw scores on BPVS did not differ significantly from those of the G-SLI subjects (t (29)=0.551, p=0.586). Finally, their memory span did not differ significantly from the memory span of the G-SLI children (t (29)=1.336, p=0.192). Thus, this group provided vocabulary and memory span controls for the G-SLI subjects (Table 1).

Design and materials

The cross-modal picture priming (CMPP) methodology for children was adopted (McKee *et al.* 1993). Which is a dual-task. Subjects listened to a sentence while they

had to respond to a visual stimulus — a picture — and decide whether it depicted a *living* or a *non-living* thing. Reaction times (RTs) were measured between the appearance of the picture on the computer screen and the pressing of one of two labelled buttons on a push-button box.

Subjects listened to 60 experimental sentences, all of which were questions, and 300 filler sentences (relation 1:5). A total of 240 fillers were declarative sentences and the remaining 60 (1:4) were questions similar to the experimental sentences. These pseudo-fillers was included to avoid a strict correlation between sentence type (question, declarative sentence) and sentence status (experimental, filler). Visual stimuli were presented in both fillers and experimental sentences and the number of animate and inanimate pictures was equal in both sentence types. The sentences made up five 10-min stories with familiar characters (e.g. *The Simpsons*, *Toy Story*), and they were spoken by two female native speakers of English at a normal speaking rate. One speaker was the narrator of the story and the second speaker was asking the questions. The sentences were recorded in an anechoic room on a Sony digital tape recorder. CoolEdit was used to edit the digital tapes, identify, and mark the points at which the visual targets were to appear.

The experimental sentences were wh-indirect object questions involving prepositional stranding. Each question was preceded by a sentence that introduced the antecedent of the gap, as shown in example (6) below:

(6) Balloo gives a long carrot to the *rabbit$_i$*.
     Who$_i$ did Balloo give the long carrot to t_i at the farm?

The antecedent was always the last word of the sentence preceding the question and there were always eight to nine syllables between the wh-word and the trace. The pictures were presented in three different positions, as shown in example (7) below:

(7) *Who$_i$* did Balloo give the long carrot to t_i at the farm?
                        ↑   ↑   ↑
                       [1]   [2]   [3]

Position [1] was at the offset of the verb. This tested whether children showed reactivation of the antecedent at the position of the verb. Position [2] was the control position. This was at the offset of an adjective within the direct object, and it was always three syllables before the gap position.[5] Position [3] was at the trace, which was always at the offset of a preposition and tested whether children show reactivation of the antecedent at the gap. In filler sentences, pictures were presented randomly within the sentences.

Two types of visual stimuli were used: a picture of the antecedent, in example (6) above *the rabbit*, or an unrelated object, *a ladder*. Previous studies applying this technique used predominantly visual targets that were strong semantic associates of the antecedent instead of the antecedent itself. A series of more recent cross-modal priming studies were followed (Clahsen and Featherston 1999, Nakano *et al.* 2002, Roberts *et al.* In press) that used as a visual target the antecedent itself. The reason for using the antecedent itself is that in this case the priming effect will be stronger than with semantic associates.

The words corresponding to the pairs of identical and unrelated pictures were matched for their frequency on the basis of the CELEX database, a database based on written and spoken material (Baayen *et al.* 1993), in order to make sure that differences in the reaction times between identical and unrelated pictures were not

due to differences in the frequency of the corresponding words (matching criterion=0.77). The same pairs of identical and unrelated pictures were presented in the three different positions in the sentences. This guaranteed that differences in RTs between identical and unrelated pictures would be the same across the three positions in the sentences.

The majority of the pictures (43/54) were from Cycowicz *et al.* (1997). As the two types of pictures were presented in three different positions, this makes a total of six experimental conditions. Each subject encountered ten sentences of each condition. Six different lists were constructed so that each subject was presented with only one of the six versions of each item. E-prime was used to control the presentation of the sentences and the pictures and to record the children's RTs.

The verbs used in the experimental sentences were all dative or beneficiate ditransitive verbs (the full list of verbs used is in Appendix B). All verbs had an age of acquisition of less than 6 years based on the Age of Acquisition ratings of Bird *et al.* (2001).

Procedure

The CMPP took place in three 20–30-min sessions at school or in the subjects' home. The first session consisted of two familiarization phases and one story and the following two sessions consisted of two stories each.

Subjects were taught the two parts (visual and auditory) of the CMPP separately. In the first session, they were told that they would play some computer games. Subjects sat in front of an E-prime push-button box and a CRT desktop monitor connected to a laptop whose screen was switched off.[6] A fixed set of instructions was given, first by the experimenter, and then through the headphones. The first familiarization phase consisted of only the visual component of the CMPP. Subjects were presented with ten pictures on the computer screen and upon presentation of each picture they had to press one of two buttons as quickly as possible. One button was designated to living things and had a picture of an animal, and a second button was designated to non-living things and had the picture of an object. Subjects received feedback after each trial and also at the end of the task; depending on whether their response was correct or incorrect, a star or a spider appeared respectively after each trial at the bottom of the screen. At the end of the task, subjects saw how many stars (correct responses) they got. After completing the first familiarization phase, subjects proceeded to the second familiarization phase that combined the visual with the auditory task and was similar to the CMPP task. Here, subjects listened to ten sentences through headphones and within each sentence a picture was presented on the computer screen. Upon encountering the picture, subjects had to perform an animacy decision task as in the first familiarization phase. In this task, half of the sentences were declarative sentences and half were questions. When presented with a question subjects had to perform the animacy decision first; after the end of the question they had to give the answer to the question orally to the experimenter. The children's responses were recorded on an answer sheet. In this way, one could check whether or not subjects comprehended the story and the questions they were asked. Subjects did not receive feedback as to whether they answered the questions correctly. The second familiarization phase was repeated

several times until subjects felt confident with the task and the experimenter was sure that subjects were performing the task properly.

After completing the second familiarization phase, subjects proceeded to the first story. Each story started with instructions for the task and twelve to thirteen declarative sentences and five questions as practice items.

Results

Analyses of accuracy

Before analysis of the reaction times, the data were screened: (1) for errors in the animacy task; and (2) for erroneous answers in the comprehension questions. One G-SLI subject's score for his comprehension of questions was more than 2 standard deviations (SDs) below the mean of the group (subject's score=67.5, group mean=88.75, SD=9.84), and was therefore excluded from further analyses. Table 2 shows the percentage of correct responses in the animacy task for the remaining participants.

A one-way ANOVA by group showed significant differences between the groups (F (2, 43)=4.655, p=0.015). Independent samples t-tests showed that G-SLI children were as accurate as their age-matched controls (p>0.1). Thus, despite their grammatical impairment, G-SLI children's performance in a task involving semantic (animacy) properties of pictures is within the normal range for their age. However, both the children with G-SLI and the CA controls performed significantly better than the LA controls (t (28)=−2.047, p=0.050; t (29)=−2.437, p<0.05).

Second, the children's comprehension of the questions was investigated. Table 3 shows the percentage of correct responses in the comprehension of questions per condition.

A mixed 3 (Group: G-SLI, CA, LA) × 3 (Position: trace, verb, control) × 2 (Target: identical, unrelated) ANOVA revealed significant main effects of Group (F (2, 41)=7.369, p<0.01, η_p^2=0.264) and Target type (F (1, 41)=21.908, p<0.001, η_p^2=0.348). There were no other main effects and no interactions. Post-hoc Bonferroni tests showed that the children with G-SLI scored significantly worse than both groups of typically developing children (G-SLI versus CA controls: p<0.01; G-SLI versus LA controls: p<0.05). Paired-samples t-tests between identical and unrelated targets revealed that in all positions children were more accurate in comprehending the question when they saw the identical picture than the unrelated picture (verb: t (43)=2.458, p<0.05; control: t (43)=3.321, p<0.01; trace: t (43)=−3.782, p<0.001). This probably reflects that in the conditions with the identical pictures, children saw the antecedent of the wh-word before answering the question, so they were primed with the correct antecedent.

Trials with errors in the animacy task and in the comprehension of the questions were eliminated from further analyses and one item was removed from the data

Table 2.   Accuracy rate in the animacy task (%)

	G-SLI		CA		LA	
	Mean	SD	Mean	SD	Mean	SD
Animacy	98.20	(1.42)	98.41	(0.79)	96.15	(3.38)

Table 3. Accuracy rate in the comprehension questions per condition (%)

		G-SLI		CA		LA	
		Mean	SD	Mean	SD	Mean	SD
Verb	identical	93.08	(12.84)	98.57	(3.06)	95.88	(4.41)
	unrelated	86.15	(11.02)	97.5	(4.70)	93.24	(8.65)
Control	identical	93.08	(8.30)	99.64	(1.34)	97.65	(3.59)
	unrelated	89.23	(10.96)	96.07	(4.46)	94.12	(5.07)
Trace	identical	93.46	(8.75)	98.93	(2.13)	97.65	(3.59)
	unrelated	87.31	(10.13)	94.29	(8.05)	95.59	(5.56)

because of a technical problem. The remaining data was screened for outliers. Reaction times above and below 3 SDs calculated by subject and item for each condition were replaced with the mean. This affected 1.04% (42 data points) of the data. No items were excluded because of errors in the animacy task or in the comprehension of questions.

Analysis of RTs

Table 4 presents the mean reaction times and standard deviations to visual targets (pictures) as well as the priming effect per condition.[7]

To investigate differences between the three groups of children in the way they process filler-gap dependencies, a $3 \times 2 \times 3$ ANOVA with two within-participants factors (Position: trace, verb, control; Target: identical, unrelated) and one between-factor (Group: G-SLI, CA, LA) by subjects (F_1) and by items (F_2) was performed. This revealed significant main effects of Position (F_1 (2, 82)=33.673, $p<0.001$, $\eta_p^2=0.451$; F_2 (2, 354)=59.043, $p<0.001$, $\eta_p^2=0.156$), Target in the items analysis (F_1 (1, 41)=0.849, $p>0.1$, $\eta_p^2=0.020$; F_2 (1, 177)=5.782, $p<0.05$, $\eta_p^2=0.018$) and Group (F_1 (2, 41)=6.119, $p=0.005$, $\eta_p^2=0.230$; F_2 (2, 177)=286.939, $p<0.001$, $\eta_p^2=0.643$). For both the subjects and items analyses there was a Position × Group interaction (F_1 (4, 82)=2.622, $p<0.05$, $\eta_p^2=0.113$; F_2 (4, 354)=8.812, $p<0.001$, $\eta_p^2=0.052$), and a Position × Target interaction (F_1 (2, 82)=4.702, $p<0.05$,

Table 4. Reaction times (RTs), standard deviations and priming effect per condition (ms)

		G-SLI		CA		LA	
		Mean	SD	Mean	SD	Mean	SD
Verb	identical	2254	(941)	1281	(550)	1759	(853)
	unrelated	2473	(968)	1328	(643)	1767	(851)
	priming	219	(236)	47	(219)	8	(325)
Control	identical	2215	(741)	1327	(574)	1827	(789)
	unrelated	2195	(761)	1247	(416)	1652	(849)
	priming	−20	(188)	−80	(241)	−175	(348)
Trace	identical	1799	(688)	998	(278)	1456	(692)
	unrelated	1767	(535)	1111	(346)	1565	(701)
	priming	−32	(514)	113	(193)	109	(147)

$\eta_p^2 = 0.103$; F_2 (2, 354)=5.067, $p<0.01$, $\eta_p^2 = 0.016$). There was also a three-way Position × Target × Group interaction for the items analysis (F_2 (4, 354)=3.373, $p=0.01$, $\eta_p^2 = 0.021$), but for the subjects analysis no significant interaction was found (F_1 (4, 82)=1.658, $p=0.168$, $\eta_p^2 = 0.075$).

To unpack these interactions, differences in the group's speed of processing on each of the three sentence positions (verb, control and trace) were first compared to establish if the G-SLI children were processing the sentences more slowly than either of the control groups. One-way ANOVAs by group for each position and target picture revealed a significant effect of Group at all positions and target pictures (trace identical: F_1 (2, 41)=6.259, $p=0.01$; F_2 (2, 177)=83.377, $p<0.001$; trace unrelated: F_1 (2, 41)=4.932, $p<0.05$; F_2 (2, 177)=33.620, $p<0.001$; verb identical: F_1 (2, 41)=6.511, $p<0.01$; F_2 (2, 177)=97.685, $p<0.001$; verb unrelated: F_1 (2, 41)=5.001, $p=0.01$; F_2 (2, 177)=65.492, $p<0.001$; control identical: F_1 (2, 41)=5.290, $p<0.01$; F_2 (2, 177)=42.171, $p<0.001$; control unrelated: F_1 (2, 41)=6.015, $p<0.01$; F_2 (2, 177)=115.452, $p<0.001$). Post-hoc Bonferroni tests revealed that children with G-SLI were significantly slower than the age controls in all conditions (trace identical: $p<0.01$; trace unrelated: $p<0.05$; verb identical: $p<0.01$; verb unrelated: $p<0.01$; control identical: $p<0.01$; control unrelated: $p<0.01$), but not the language controls ($p>0.09<0.45$). Thus, based on the G-SLI children's speed of processing and given that G-SLI children's memory span was similar to the memory span of the language controls, one might expect that their priming pattern would be similar to their language controls, but not their age controls. Thus, in the second set of analyses the priming effects were investigated by conducting a 3 × 2 ANOVA for each group separately.

CA control children

The 3 (Position: trace, verb, control) × 2 (Target: identical, unrelated) ANOVA for the CA controls revealed a main effect of Position (F_1 (2, 26)=7.057, $p<0.01$, $\eta_p^2 = 0.352$; F_2 (2, 118)=20.349, $P<0.001$, $\eta_p^2 = 0.172$) and a significant interaction between Position and Target in the by items analysis (F_1 (2, 26)=2.857, $p=0.076$, $\eta_p^2 = 0.180$; F_2 (2, 118)=3.276, $p<0.05$, $\eta_p^2 = 0.032$). To investigate the cause of this interaction, paired-samples t-tests were conducted. These showed no significant effect at the verb ($p>0.1$), or at the control position ($p>0.1$), but a significant difference at the trace (t_1 (13)=−3.720, $p=0.001$; t_2 (59)=−3.266, $p<0.01$). Thus, the identical picture significantly facilitated RTs at the trace position but not at either the verb or the control position. This indicates that age-matched controls process wh-questions through a filler-gap dependency between the antecedent and the trace.

LA control children

The 3 × 2 ANOVA for the LA controls revealed a main effect of Position (F_1 (2, 32)=9.436, $p<0.01$, $\eta_p^2 = 0.371$; F_2 (2, 118)=12.345, $p<0.001$, $\eta_p^2 = 0.095$) and a significant interaction between Position and Target (F_1 (2, 32)=4.213, $p<0.05$, $\eta_p^2 = 0.208$; F_2 (2, 118)=5.700, $p<0.01$, $\eta_p^2 = 0.046$). Paired-samples t-tests showed no significant effect at the verb ($p>0.1$), but a significant difference at the control position (t_1 (16)=−2.068, $p=0.055$; t_2 (59)=2.512, $p<0.05$), and a significant difference at the trace (t_1 (16)=−3.066, $p<0.01$; t_2 (59)=−2.246, $p<0.05$).

At the control position, RTs at the identical targets were significantly *longer* (1827 ms) than at the unrelated targets (1652 ms). Recall that the control position was not lexically or syntactically relevant for the interpretation of the sentence. Thus, the antecedent of the wh-word at a lexically or syntactically unrelated position appears to cause an interference effect, thereby slowing down processing. In contrast, there was a priming effect at the position of the trace, as RTs at the identical targets were shorter (1456 ms) than at the unrelated targets (1565 ms). These data indicate that young 8–9-year-old children matched with the G-SLI children on their vocabulary and memory span process wh-questions through a filler-gap dependency between the antecedent and the trace.

G-SLI children

The 3×2 ANOVA for the G-SLI children revealed a main effect of Position (F_1 (2, 24)$=$15.795, $p<0.001$, $\eta_p^2=0.568$; F_2 (2, 118)$=$31.019, $p<0.001$, $\eta_p^2=0.231$) and, a significant interaction between Position$\times$Target (F_1 (2, 24)$=$4.260, $p<0.05$, $\eta_p^2=0.436$; F_2 (2, 118)$=$3.384, $p<0.05$, $\eta_p^2=0.032$). Paired-samples *t*-tests showed no significant effect at the control position ($p>0.1$) or at the trace position ($p>0.1$), but a significant difference at the verb (t_1 (12)$=-3.340$, $p<0.01$; t_2 (59)$=-2.836$, $p<0.01$). At the position of the verb, RTs at the identical targets were significantly shorter (2254 ms) than at the unrelated targets (2473 ms). This indicates a priming effect at the position of the verb. In contrast, no reliable differences were attested at the position of the trace. This indicates that children with G-SLI process wh-questions through a lexical/thematic association between the antecedent and the verb rather than through a syntactic dependency between the antecedent and the trace. However, it should be noted that there was considerable individual variation in the data with respect to priming effects at the trace, with almost equal numbers of G-SLI showing positive priming (6/13) as negative priming (7/13) with a wide range of -1288 to $+694$ ms. In contrast, at the verb all but one G-SLI child showed positive priming, with 10 out of the 13 children showing priming of more than 100 ms. Note this variability in priming performance at the trace across the G-SLI teenagers, but consistent priming at the verb, is exactly what the CGC predicts if computing syntactic dependencies involving movement is optional and lexical knowledge is used instead.

Correlations between priming effects and working memory

To investigate whether there is a relation between priming effects and working memory, a number of Pearson correlations between the score of the working memory task and the priming effect at each of the three positions for the overall group and on an individual group basis were conducted. However, all correlations for all three positions were low and non-significant ($p>0.3$), indicating that there were no systematic relations between the priming effects and working memory.

Discussion

This study investigated the processing of wh-questions in a subgroup of G-SLI children using on-line methodology to explore their accuracy, speed of processing,

and whether or not they process questions qualitatively differently from children of a similar age or vocabulary language ability.

The results revealed that G-SLI children were as good as their age-matched controls in judging animacy properties of pictures. However, although they showed a high accuracy score in the comprehension of questions (90% correct), their comprehension was significantly lower compared with both their age and vocabulary controls. In contrast, their speed of processing did not differ from their vocabulary controls that had similar memory span to the G-SLI children, but was significantly slower than their age controls, that also had a higher memory span than the children with G-SLI. In other words, the G-SLI children's speed matched that of the TD children with similar language abilities and memory span, rather than age. This finding is consistent with previous investigations in sentence processing of children with SLI (Montgomery *et al.* 1990, Stark and Montgomery 1995, Montgomery 2000, 2002). However, the present study also revealed qualitative differences in processing syntactic dependencies involving movement between G-SLI and TD children. Age-matched controls and vocabulary controls matched on memory span to the G-SLI children showed a priming effect at the position of the trace. In contrast, G-SLI children evinced no priming at the trace. Instead, they showed priming at the position of the verb. This finding cannot be accounted for by processing limitations due to lower memory span, or limited vocabulary as the present G-SLI and vocabulary controls did not differ on memory span or vocabulary and no systematic relations were revealed between memory and priming effect for the children in this study. Thus, the data suggest that children with G-SLI comprehend wh-questions by using lexical/thematic or discourse representation instead of syntactic information.[8]

Off-line and on-line investigations of Wh-questions in children with G-SLI

In order for children to produce and comprehend wh-questions, they have to be able to compute syntactic dependency relations (movement) of the auxiliary from I-to-C (head movement) and the wh-word to the specifier of the CP (wh-movement). Results of this study combined with results from previous studies indicate that in TD children, computing such syntactic dependencies has already been established at a very young age (Stromswold 1995, Love and Swinney 1997, Roberts *et al.* In press). However, off- and on-line results from children with G-SLI show a different pattern.

Off-line studies revealed that children with G-SLI produce and accept wh-questions with errors related both to I-to-C and to wh-movement (van der Lely and Battell 2003), and the present study advances our understanding of *how* G-SLI children process questions in real time. In contrast to TD children, children with G-SLI showed no priming effect at the position of the gap, but instead they exhibited a priming effect at the subcategorizing verb. Thus, in the absence of establishing a syntactic dependency between the filler and the gap, the results indicate that children with G-SLI construct a lexical association between the antecedent and the verb or use discourse representation to interpret the question. This can account for how the children with G-SLI were able to comprehend the majority of the wh-questions. Whereas a reliance on lexical–semantic and discourse information is often sufficient to process and interpret questions, it appears from their lower comprehension scores that it is not as reliable as fully automatized syntactic processing.

The paper will now consider two alternative explanations of these data. One possibility could be that children with G-SLI are garden-pathed at the position of the verb. In a scenario as in (8) below, they could postulate a gap [t_1] after the verb *give* and attempt to integrate the wh-word *who* as a dative indirect object of the verb:

(8)   Balloo gives a long carrot to the rabbit.
       Who did Balloo give [t_1] the long carrot to [t_2] at the farm?

This could explain the priming effect at the verb. Then on encountering the preposition *to*, they would have to revise their hypothesis and postulate a gap [t_2] after the preposition. Lack of priming at this position could indicate their inability to re-analyse the wh-word as the complement of the preposition *to*. Although based on this study, it is impossible to rule out this possibility, there are several reasons against adopting an interpretation along those lines. First, the indirect object in the declarative sentence preceding the question was always expressed through a prepositional phrase (e.g. *Balloo gives a long carrot to the rabbit*) and was never in a dative frame (e.g. *Balloo gives the rabbit the long carrot*). Therefore, participants were always primed with an argument structure involving a prepositional phrase and never with a dative construction. Previous research has shown that children with SLI are sensitive to structural priming and are more likely to use a particular structure when they have just heard a sentence with this structure (Leonard *et al.* 2000, 2002). Second, children with SLI rarely use the dative construction, but they do use prepositional phrases (van der Lely and Harris 1990). Finally, dative constructions involving full noun phrases even in TD children are acquired later than preposition phrases (Snyder and Stromswold 1997). Therefore, the present authors consider it unlikely that priming of the antecedent at the verb in children with G-SLI was due to them postulating a dative gap and then failing to re-analyse the sentence.

A further explanation for the lack of priming effect at the trace for the children with G-SLI could be related to the fact that processing demands increase with the length of the sentence. The position of the verb was earlier in the sentence than the position of the trace. If children with G-SLI have limited processing capacity, then this could explain why they showed a priming effect at the verb, but not at the trace. Although this possibility can also not be conclusively ruled out on the basis of the present study, if memory span is an indicator of processing capacity, then the LA controls should also fail to show a priming effect at the trace and instead show priming at the verb, if this is caused by processing capacity limitations. Given that LA controls did show a priming effect at the trace, it was considered that the lack of a priming effect at the trace in G-SLI children does not result from processing capacity limitations.

Implications for accounts on SLI

This section will now discuss how the present data can be accommodated within the Generalized Slowing Hypothesis and the CGC hypothesis.

First, the finding that G-SLI children showed longer reaction times than age-matched controls but not language-matched controls is consistent with the Generalized Slowing Hypothesis. However, it is difficult to accommodate the discovery that G-SLI children appear to be primarily using lexical–semantic, or

discourse but not syntactic information to process wh-questions as evinced by the priming effect at the verb but not at the trace position. Is it possible that the G-SLI children's slower processing rate or memory capacity limitations could have caused the difference in priming between the G-SLI and control children? Although one cannot conclusively discard this possibility based on the present data, it is thought that this is unlikely because this explanation is not parsimonious given the data from the vocabulary-matched controls. These 8–9-year-old children responded to primes at a similar rate and have similar memory span as the G-SLI children; yet they showed the same priming at the trace position as the older age-matched controls, rather than the priming pattern shown by the G-SLI children.

In contrast, the prediction from the CGC — that precisely this filler-gap, syntactic dependency would be impaired in G-SLI children — is supported. The lack of priming at the gap position indicates that SLI children do not process wh-questions through establishing a syntactic filler-gap dependency, i.e. feature checking involving movement, but rather through a lexical–semantic or discourse information. Further the results support the claim that G-SLI children sometimes merge the wh-word directly to the specifier of the CP (van der Lely and Battell 2003). Further research is warranted to investigate the neural correlates of such syntactic dependencies to establish whether the processing differences found in the present study translate into qualitative differences in neural brain systems.

A question remains as to how generalizable these findings are to other groups of children with SLI. Previous replications of van de Lely, and colleagues' studies of G-SLI in non-differentiated groups of children with SLI have shown remarkably similar findings, albeit that some children with SLI might also have had other co-occurring deficits (Precious and Conti-Ramsden 1988, O'Hara and Johnston 1997, Bishop *et al.* 2000, Norbury *et al.* 2001, 2002). Furthermore, cross-linguistic data in typologically different languages (e.g. Hebrew) show that many groups of SLI children, some clearly with G-SLI, exhibit very similar deficits in wh-questions. However, we are cautious in their conclusions: it is quite plausible that very different underlying deficits cause the same surface behaviours. It is only through further careful investigation of the different phenotypes and eventually their genotypes that one will start to understand this complex developmental issue.

The findings from this study have implications for therapy. First, they allow us to identify more accurately the locus of the deficit and the precise nature of that deficit. Further, they indicate that the G-SLI children might be using lexical/semantic and discourse knowledge and mechanisms to a greater extent than typically developing children. Thus, results such as these would allow speech-and-language therapists to target their remedial programmes more precisely. An unanswered question, however, is whether therapy should be directed at the defect — perhaps through some meta-syntactic therapy — or whether it should focus on developing compensatory (semantic) strategies. In addition, it would be valuable to discover whether similar syntactic deficits can be found in other subgroups of SLI children, with less discrete grammatical deficits than the G-SLI subgroup. As effective remediation is likely to depend on aetiological insight, such detailed phenotypic characterization is valuable for clinical practice.

Conclusions

This study revealed differences in speed and patterns of processing between TD children and children with G-SLI. First, the findings indicate that speed of processing develops as a function of language ability and memory rather than only age: G-SLI children were slower than their age but not their vocabulary and memory controls. This indicates that language abilities, memory capacity as well as age determine processing speed. The differences in speed of processing between TD children and children with G-SLI cannot distinguish between the Generalized Slowing Hypothesis versus the CGC account of G-SLI because slower speed of processing per se could result from either impaired general processing or from impaired representations and/or mechanisms underlying the construction of syntactic dependencies within hierarchical grammatical structures. In contrast, the pattern of processing can illuminate this issue. It was found that TD children process wh-questions by constructing a syntactic dependency between the filler and the gap, as evinced by a reactivation of the antecedent at the position of the trace. In contrast, children with G-SLI showed reactivation at the position of the verb, but not at the trace. This indicates that instead of establishing a syntactic dependency between the filler and the gap, they process wh-questions through a lexical–thematic association between the verb and its arguments or through discourse information. This pattern of processing concurs with previous findings from off-line experiments in the production and judgement of wh-questions. Although the Generalized Slowing Hypothesis cannot conclusively be ruled out, these data challenge this hypothesis. However, the data support the CGC hypothesis, according to which children with G-SLI are impaired in forming syntactic dependencies involving movement. Thus, at times they might merge the wh-word directly at the specifier of the CP. Finally, this study showed that complementing off-line with on-line methodology in a systematic way enhances one's understanding in the underlying representations and processing mechanisms of children with typical and atypical development.

Acknowledgements

Notes

1. In this study, although theoretically distinguishable, as in other behavioural and imaging studies, one cannot distinguish between representations and processing mechanisms underlying those representations. This also includes distinguishing the building of representation from the so-called 'parser' for sentence processing. It is acknowledged that this is a complex but important issue that

remains to be solved. Research into early language acquisition and second language learning indicates that the relations are bidirectional.

2. A reviewer questioned about how 'move' could be optional. Of course, one can only speculate, but two possibilities are: (1) the mechanism or algorithm underlying that mechanisms may be defective such that a 'steady-state' in learning is never achieved; or (2) a compensatory mechanism could be being used.

3. Scores on TROG should be taken as a general guide to the SLI subject's grammatical knowledge as this test assesses a range of abilities, not only those that are problematic for G-SLI children.

4. Some readers might question why children with so-called G-SLI have any vocabulary deficits: the probable answer is because lexical learning requires many skills including syntactic cues to word meaning (Bloom 2000). Furthermore, later lexical learning of abstract nouns and verbs is more dependent on syntax than earlier learning. Later lexical learning also relies to a greater extend on reading — another secondary problem found in many children with SLI.

5. Several studies have used as a control position 500 or 700 ms before the gap. However, if the control position is always a certain amount of ms before gap position, it is sometimes in the middle of a word. In this case, longer reaction times at the control position as opposed to the gap position may result from presenting the visual stimuli in the middle versus at the offset a word. To avoid this possible confounding factor, the control position in this experiment was always the offset of a word preceding the gap.

6. The monitor of the laptop is not used because laptop displays do not use raster technology to redraw the screen. Without being able to judge the position of the raster, it is not possible to guarantee the synchronization of each display, and to guarantee that the refresh rate is accurate.

7. RTs in this task were overall longer than in studies using this methodology with healthy adult populations, in which RTs are often around 500–700 ms. However, RTs in children are typically longer. Two studies with TD children using the same methodology have reported RTs around 1500 ms (McKee *et al.* 1993, Roberts *et al.* In press). In those studies, children had to listen to one sentence and perform a dual task. In the present studies, children had to listen to two sentences (a declarative sentence and a question), and while listening to the second sentence, the question, they had to perform the dual task. This is probably the reason why the RTs of the TD children are slightly longer than in the studies mentioned above (1000–1800 ms). RTs of the children with G-SLI were longer than in TD children, which is not surprising given the language impairment. The discrepancy between TD children and children with G-SLI is similar to the discrepancy found between healthy adults and adults with aphasia using the same methodology. There are two studies using the same methodology investigating filler-gap dependencies in Broca's and Wernicke's patients (Zurif *et al.* 1993, Blumstein *et al.* 1998). In the study by Zurif *et al.*, RTs of the aphasic patients were between 900 and 1200 ms; whereas in the study by Blumstein *et al.*, RTs were between 1100 and 1850 ms. What is crucial in the present task is that participants performed the dual task before they answered the comprehension question, i.e. before they processed the entire sentence and consciously thought about the meaning of the sentence. Therefore, it is believed that despite the longer than usual RTs, this task still tapped into processing of the sentence as it unfolds.

8. One reviewer questioned whether children with G-SLI make use of lexical/semantic information of the verb or discourse representation, given that children heard in the previous sentence a declarative version of the wh-question. It is agreed that this is a possible scenario, but one cannot disentangle these two possibilities based on the material from the present study.

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Appendix A: Individual performance of children with G-SLI for matching and selection

Subjects	Age	TROG, raw score	TROG, z-score	ITPA, raw score	ITPA, z-score	BPVS, raw score	BPVS, z-score	Non-verbal IQ	VATT, raw score (n=40)	VATT, per cent errors	Memory span
HC	10;2	14.0	−1.4	6	−4.00	88.0	−0.2	94.0	6	85	1.0
QC	10;6	12.0	−1.7	17	−4.67	61.0	−1.9	86.0	12	70	2.5
PR	11;6	13.0	−1.7	11	−5.67[a]	77.0	−1.3	92.6	1	97.5	2.5
SL	11;9	9.0	−2.5			74.0	−1.7	95.5	4	90	3.0
GS	12;5	11.0	−2.3			92.0	−0.8	87.3	4	90	2.5
LJ	13;1	16.0	−1.2[a]	25	−2.00[a]	92.0	−1.2	107.5	29	27.5	1.5
RP	13;2	16.0	−1.2[a]	22	−3.17[a]	98.0	−1.3	85.0	28	30	2.5
WS	13;4	16.0	−1.2[a]	26	−1.50[a]	113.0	−0.1	107.5	32	20	3.0
TD	13;8	15.0	−1.6[a]	18	−4.83[a]	84.0	−1.5	89.0	21	47.5	3.0
SM	14;0	15.0	−1.0[a]	21	−3.67[a]	92.0	−1.6	117.3	5	87.5	2.5
BS	14;5	13.0	−2.2[a]	12	−5.83[a]	65.0	−2.9	88.4	27	32.5	1.5
GD	14;6	17.0	−0.7[a]	21	−3.67[a]	99.0	−1.8	93.4	11	72.5	2.5
CM	16;11	17.0	−0.7[a]	25	−2.00[a]	104.0	−1.9[a]	98.6	24	40	2.0
DA	17;2	17.0	−0.7[a]	27	−1.17[a]	107.0	−1.8[a]	87.0	1	97.5	2.0

[a]Children's ages fall outside the standardization of this test. The z-scores for TROG were computed based on children of 12 years of age, the z-scores on BPVS were computed based on children of 15 years of age, and the z-scores for the Illinois Test of Psycholinguistic Abilities (ITPA) were computed based on children of 10 years of age. Thus, they should be interpreted with caution.

Appendix B: Verbs used in the cross-modal priming experiment

bring for/to	make for
build for	paint for
buy for	pass to
dig up for	pick up for
draw for	post for
fetch for	show to
find for	stir for
get for	take for/to
give to	throw to
grab for	
kick to	