1+ model NEL : 348 Prod.Type:FTP pp.1–19(col.fig.:NIL) ED:SreejaGA PAGN:Bhaskara SCAN:

ARTICLE IN PRESS

ELSEVIER

Journal of Neurolinguistics ∎ (∎∎∎∎) ∎∎∎–∎∎∎

Journal of NEUROLINGUISTICS

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Recognition of gated verbs by children with Grammatical-Specific Language Impairment: Effects of inflection and frequency

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Received 28 November 2006; received in revised form 22 October 2007; accepted 23 October 2007

Abstract

A common feature of language disorders, particularly in English, is an impairment in inflectional morphology. One view claims that this deficit is caused by impaired speech processing and resulting impoverished phonological representations. We investigated the accuracy of spoken word recognition in Specific Language Impairment (SLI) using a successive forward gating paradigm, with target verbs manipulated for frequency and past tense inflection. Children with Grammatical-SLI were compared to age and language controls. We scored responses according to (1) proportion of gates to the first correct response, (2) proportion of gates to the first of three consistently correct responses. G-SLI children generally performed at the same level as age and vocabulary controls, although worse than age controls on uninflected verbs with respect to the second criterion, indicating that they activated the correct word at the same point, but took longer to reach a consistent response. Low frequency and inflection of the target word did not disadvantage G-SLI children to a greater extent than any of their controls. These results do not support the hypothesis that G-SLI children's morphological impairment is caused by poor acoustic-phonetic processing.

Keywords: SLI; Gating; Inflectional morphology; Lexical access

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doi:10.1016/j.jneuroling.2007.10.003

1. Introduction

Children with Specific Language Impairment (SLI) have significantly impaired language acquisition in the absence of any obvious cause, such as hearing loss, low non-verbal IQ, motor difficulties or neurological damage (Leonard, 1998). Production of syntactically simple sentences, errors in inflectional morphology, poor phonological abilities and delayed lexical acquisition are characteristic of SLI (Bishop, 1997; Leonard, 1998). However, the nature of the underlying deficit is vigorously debated (Joanisse & Seidenberg, 1998; Leonard, 1998; van der Lely, 2005). One hypothesis is that it is specific to grammar itself, affecting either the tense system, relations between different syntactic constituents, or complex grammatical structures more generally (Jakubowicz, 2003; Rice, Wexler, & Cleave, 1995; van der Lely, 1998, 2005). An alternative hypothesis is that children with SLI have impoverished phonological representations, and that this impacts on their acquisition of words, morphology and sentence structure. This phonological deficit is in turn claimed to be caused by an underlying deficit in processing the rapid temporal transitions characteristic of speech or by a more general processing deficit (Joanisse & Seidenberg, Q1 1998; Kail, 1994; Leonard, 1998; Tallal & Piercy, 1974).

The issue of what underlies SLI is not easy to resolve because the range of language impairments and their level of severity, stage of resolution and degree of compensation all vary greatly between individuals. Because SLI is highly heterogeneous, a single explanation is unlikely to be able to account for the broad range of impairments, and this heterogeneity makes it difficult to test linguistic and cognitive models of the disorder. One way of dealing with the heterogeneity is to identify subgroups of SLI children whose members share a common profile of linguistic strengths and weaknesses. van der Lely and her colleagues have identified a group of children, termed Grammatical (G)-SLI, whose difficulties with language appear to be confined to the core aspects of structural grammar—syntax, morphology and phonology (van der Lely, 1996a, 1997a, 1997b, 1998, 2005; van der Lely, Rosen, & McClelland, 1998; van der Lely & Stollwerck, 1997).

Crucial to the characterisation of G-SLI are (1) the persistence of the deficit over the age of 9, and (2) the particular pattern of grammatical impairment. The Computational Grammatical Complexity Hypothesis, developed to account for G-SLI, claims that the linguistic deficit lies in the formation of complex hierarchical structures within syntax, inflectional morphology and phonology (Marshall, 2006; Marshall & van der Lely, 2007a, 2007b; van der Lely, 2005). Within syntax, particular difficulties are evinced when syntactic dependencies involving 'movement' are required, such as the use of subordinate clauses (van der Lely et al., 1998), wh-question formation (van der Lely & Battell, 2003), the assignment of thematic roles in passive sentences (van der Lely, 1996b). In terms of morphology, difficulties are with creating regular inflected, and hence hierarchically complex, forms. G-SLI children omit past tense inflection at high rates (Marshall & van der Lely, 2006; van der Lely & Ullman, 2001), judge bare stem forms as acceptable in a past tense context (van der Lely & Ullman, 1996) and ungrammatically produce regular plurals inside compounds and derived forms (Marshall & van der Lely, 2007a; van der Lely & Christian, 2000). Although their articulation is intelligible, initial work has revealed subtle phonological deficits in hierarchical structure, affecting consonant clusters and words containing unfooted syllables (Gallon, Harris, & van der Lely, 2007; Marshall, 2006; Marshall, Harris, & van der Lely, 2003). In contrast, derivational suffixation is unimpaired in these children (Marshall & van der Lely, 2007a), and they are able to use referential expressions to produce a cohesive and structured narrative discourse (van der Lely, 1997a). They have no difficulty producing negation, a syntactic construction that does not involve movement (Davies, 2002).

There is widespread controversy as to whether an auditory processing deficit—either specific to speech or more general in nature—can account for the varied language impairments seen in SLI children. On the one hand, numerous studies have found that groups of SLI children perform poorly on a range of tasks tapping non-speech and speech perception processes, such as temporal order judgement tasks and categorical perception (Joanisse, Manis, Keating, & Seidenberg, 2000; Leonard, McGregor, & Allen, 1992; Stark & Heinz, 1996; Tallal & Piercy, 1974; Ziegler, Pech-Georgel, George, Alario, & Lorenzi, 2005). These findings are potentially relevant to explaining the marked deficit in past tense morphology that is characteristic of English-speaking children with SLI. The different forms of the past tense morpheme, /t/, /d/ and /ɪd/ are perceptually non-salient: they are stop consonants that tend to be unreleased word-finally and are brief in duration. Such sounds are particularly difficult for children with SLI to process (Stark & Heinz, 1996; Tallal & Piercy, 1974). Leonard et al. (1992) found that sounds of brief duration are especially difficult for children with SLI to perceive if they occur adjacent to other material of longer duration, as is the case with verbal inflection.

Results from studies of speech processing have formed the basis of connectionist models of SLI (Joanisse, 2004, in press). The premise is that difficulties in perceiving speech proximally affect phonological development, and that this phonological deficit causes impairments in morphology and syntax. With regards to the English past tense, the deficit causes problems in learning the consistency of the phonological relationship between regular stems and their past tense forms (e.g. *walk* and *walked*) and the commonalities amongst regular past tense forms (e.g. *walked*, *jumped*, *hugged*, *splashed*). In other words, phonological deficits are the link between perceptual and past tense impairments. When the phonological layer in a connectionist network is disrupted by random noise to simulate a speech processing deficit, hence making it more difficult for the network to accurately encode phonological forms, the past tense deficit seen in SLI children is reproduced.

On the other hand, not all researchers are convinced by the presence of a speech processing deficit in SLI. Coady, Kluender, and Evans (2005) claim that children with SLI perceive natural speech comparably to age-matched controls when listening to words under conditions that minimise memory load. Montgomery (1995) found differences between SLI and control groups in their ability to discriminate between four-syllable non-words that differed in a single phoneme, but failed to find differences in discrimination abilities at shorter syllable lengths, again supporting the notion that memory load, and not speech perception, is the critical factor. A further issue is that in most studies reporting perceptual deficits, a proportion of SLI participants perform normally, which strongly suggests that while perceptual deficits are associated with SLI, they are not necessary or sufficient to cause SLI (see Rosen, 2003, for further discussion).

There is as yet no evidence that a consistent deficit in auditory processing more generally, or speech perception in particular, could account for the profile of language difficulties found in G-SLI children. Although a significant number of children with G-SLI do have difficulties processing non-speech and speech material, many do not. For example, van der Lely, Rosen, and Adlard (2004) carried out a set of same/different judgement tasks and found that for non-speech formant transitions, 69% of G-SLI children showed normal auditory processing compared to age-matched controls, and for rapidly presented tones, 46% did so. Only 31% had normal identification of synthesised speech tokens /ba/ and /da/. The G-SLI children were no slower at processing non-speech and speech material than their age-matched controls. Importantly, there was no relationship between performance on these tasks and the severity of language impairments, a relationship that would be expected if perceptual impairments were the cause of the language impairment. van der Lely and her colleagues therefore argue that the deficits found in G-SLI children cannot be caused by an underlying perceptual deficit (van der Lely, 2005; van der Lely et al., 1998, 2004). However, the efficiency with which phonological representations support lexical access have not yet been investigated in this group, and indeed has been little researched in SLI children more generally (for exceptions, see Dollaghan, 1998; Mainela-Arnold, Evans, & Coady, 2005; Montgomery, 1999). Similarly, there has been little work on how children with SLI access inflected forms, testing how a deficit in speech perception might impact directly on the recognition of past tense inflection.

With recent genetic evidence pointing to SLI being a multi-factorial disorder (Bishop, Adams, & Norbury, 2006; Fisher, 2006; SLI Consortium, 2002), it is becoming clear that precise descriptions of linguistic and non-linguistic behaviour in children with SLI are needed in order to investigate the relationship between phenotypes and genotypes (Ramus, 2006). In this paper, we add to a large body of psycholinguistic work previously carried out with G-SLI children. We use a successive forward gating study to examine the nature of G-SLI children's acoustic-phonetic representations. Specifically, we investigate how efficiently these representations are used in lexical access and the recognition of inflected forms.

In the successive forward gating paradigm, increments of an auditory input signal are presented, starting at the word onset, until recognition occurs (Grosjean, 1996). Various response measures can be calculated, including the proportion of gates to first correct response, the participant's confidence in that response, and the proportion of gates to first meaningful response (as opposed to a phoneme or non-word). Because target words are presented without any supporting context, the method affords a direct examination of acoustic-phonetic processing, and measures the efficiency of basic lexical access and word identification. It is not a timed task (although participants are instructed to respond immediately after hearing the stimulus) but rather a mixed on-line/off-line measure.

The methodology is appealing to researchers of SLI because (1) it enables us to measure lexical access in a task that does not require word naming, recall, categorisation and recognition in sentence contexts, skills that might be impaired in this population, (2) its working memory demands are low, and (3) the impact of group differences in response speed and latency are minimised (Dollaghan, 1998). Dollaghan investigated the effect of word familiarity on SLI and age-matched control groups, comparing performance on familiar and recently taught (earlier in the same experimental session) words. She found that SLI and age controls did not differ in the proportion of gates required to make their first correct response to familiar words. However, the SLI children required a higher proportion of gates before recognising the newly taught words. Dollaghan's conclusion is that children with SLI are less successful in representing the critical phonological characteristics of new words in their lexicons so as to distinguish them from existing, phonologically related word entries.

Montgomery (1999), in contrast, found no difference between SLI and their age-matched and vocabulary-matched controls on a variety of response measures, although the target words he presented were all familiar ones. He concluded that SLI children do not differ from their typically developing peers in auditory word recognition. Mainela-Arnold et al. (2005) found that SLI children and their age-matched controls made their first correct identification of words after the same proportion of gates, but that SLI children vacillated between several words before they finally settled on the correct one. This was particularly so if the word was from a low-density neighbourhood. In sum, the evidence suggests that SLI children do not show greatly impaired acoustic-phonetic analysis and word recognition abilities compared to their age-matched peers, but that they are disadvantaged when target words are newly learnt or have sparse neighbourhood sizes.

If children with SLI have a speech processing deficit and consequent phonological impairments, how would this make itself manifest in a gating task? In other words, what is it about the gating task that requires good perceptual and phonological abilities? We assume the Cohort Model of auditory word recognition (Marslen-Wilson, 1984, 1987). In this model, when the first 200 ms or so of a word is heard, a cohort of possible word candidates is activated. When more of the word becomes audible, candidates that no longer match the incoming information are deactivated, until only one candidate remains. The gating procedure measures at which point in the word the target candidate is recognised. Recognition requires the mapping of the incoming word, or portion thereof, onto the phonological representation of the matching lexical item. Consequently, there are two parts to this process which require good speech perception and phonological skills: firstly, the creation of a representation of the incoming stimulus, and secondly, the representation of the lexical item to be activated. Both of these aspects might be expected to be problematic for a child with perceptual and phonological impairments, potentially making the mapping process slower. For example, if phonological representations are underspecified in some way, as has been claimed (Joanisse, in press), then a larger cohort of words might be activated at the earliest gates and be eliminated at a later proportion of gates compared to typically developing children. SLI children might potentially require more time for word recognition and be less efficient in retrieving the correct word.

In connectionist models, frequency and neighbourhood densities are important factors in determining lexical acquisition, and previous gating studies indicate that children with SLI are indeed sensitive to these factors. Dollaghan's (1998) finding that children with SLI require more gates compared to age-matched controls in order to recognise newly taught words suggests that these words are more weakly represented and competitors are eliminated later than is the case for their peers. Mainela-Arnold et al.'s (2005) finding that children with SLI vacillate more between competing lexical items, particularly when those items are from low-density neighbourhoods, suggests that during the process of eliminating competing candidates they are less facilitated by activation from similar sounding words.

In our gating task, we investigate a word structure that children with SLI find particularly problematic: regular past tense inflection. We compare recognition of uninflected and inflected forms. The recognition process for uninflected and inflected words consists of selecting a lexical item on the basis of eliminating alternative candidates and identifying the actual word form. Critically, inflected forms involve weak particles that have to be acoustically processed in order to recognise the word, whereas this is not the case for uninflected forms. Identifying inflected word forms should therefore be difficult for G-SLI children if they have a difficulty in acoustic processing.

Would we expect G-SLI children to access inflected forms in the same way as typically developing children? The answer depends on whether one assumes that inflected forms are stored in the lexicon, and there is much debate over this (e.g. Clahsen, Hadler, & Weyerts, 2004; Pinker & Ullman, 2002; Stemberger & MacWhinney, 1986). There is evidence that G-SLI children store regular past tense forms but that typically developing children, at least from the age of six, do not. For G-SLI children, a past tense elicitation task revealed effects of frequency for regular past tense inflection for G-SLI children but not for typically developing controls, whereas all children showed frequency effects for irregular past tense forms (van der Lely & Ullman, 2001). These results led van der Lely and Ullman to claim that G-SLI children preferentially store regular past tense forms rather than creating them *de novo* in the way that typically developing children do. The process of mapping the incoming acoustic-phonetic stimulus of an inflected form to the lexicon might then be expected to be different in G-SLI children compared to typically developing children: for stored inflected forms the incoming stimulus has to be mapped directly on to a [stem + suffix] form, whereas for inflected forms that are not stored whole, the stimulus has instead to be mapped onto two separate morphemes, [stem] + [suffix]. Whether there is a difference in efficiency between these two processes is not immediately obvious.

We assume that G-SLI and typically developing children access uninflected forms in the same way. It is possible, given van der Lely and Ullman's (2001) study, that G-SLI children access inflected forms in a different way to their typically developing peers. However, and importantly, access to the stored inflected form and/or to the past tense suffix is predicted to be harder for G-SLI children if they have a speech processing deficit that leaves the suffix particularly vulnerable in the incoming acoustic-phonetic stimulus. They will therefore need a higher proportion of gates in order to identify the inflected form of the verb. One potential problem is that because the acoustic cues to inflection only occur towards the end of the word, recognition of inflected forms will necessarily require a larger proportion of gates than uninflected forms: there is therefore less possibility of between-group variability. However, if inflection is particularly hard for G-SLI children to perceive, we would still predict a group by inflection interaction. In contrast, if we find no group by inflection interaction and children with G-SLI show good recognition of inflected forms, this would be evidence against the hypothesis that a difficulty in perceiving the past tense suffix causes, or contributes to, the morphological deficit in G-SLI.

As well as manipulating the inflection on the verb, we also manipulate frequency, as this provides insight into the robustness of children's phonological representations (Dollaghan, 1998). Furthermore, G-SLI children show frequency effects for verb inflection: they are more successful at inflecting high frequency verbs compared to low frequency forms (van der Lely & Ullman, 2001). We predict that high frequency forms will require a lower proportion of gates. If we find a group by frequency effect, with the G-SLI children showing particular poor performance for low frequency forms, this would indicate that G-SLI children have poor phonological representations supporting lexical access.

Because the acoustic changes marking inflection occur close to the end of the word, this may not leave much room for frequency to have an effect within inflected forms. We might therefore expect a frequency by inflection effect, with recognition easiest for high frequency uninflected forms. The question is then whether this effect is the same for all groups, or whether G-SLI children behave differently with respect to frequency and inflection.

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2. Method

2.1. Participants

Sixteen participants were selected for the G-SLI subgroup. All had taken part in previous studies, including those reported in van der Lely et al. (2004) and Gallon et al. (2007). They were aged between 10.5 and 17.0 (mean age 13.3) at the time of the present study, and were being educated at, or had just left, specialist schools for children with SLI. All had persisting grammatical deficits in comprehension and production. In particular, each child made at least 20% errors on a test of third person agreement and past tense, the Verb Agreement and Tense Test (van der Lely, 2000), and at least 20% errors on the Test of Active and Passive Sentences (van der Lely, 1996b), a comprehension task. Previous work has shown that children over the age of 8 years very rarely make errors on these tasks (van der Lely, 1996a; van der Lely & Ullman, 2001). However, G-SLI participants' non-verbal cognitive abilities were within normal limits (i.e. a standard score of 85 or above, as measured by either the Raven's Progressive Matrices (Raven, 1998) or the Block Design subtest of the British Ability Scales (Elliott, 1996), and they suffered no hearing loss. None exhibited social or emotional difficulties, autistic-like difficulties, or semantic-pragmatic difficulties, on report of their Speech and Language Therapist. None had articulatory dyspraxia or severe phonological disorders that affected intelligibility.

Table 1 shows G-SLI children's standard scores for the Clinical Evaluation of Language Fundamentals (CELF; Semel, Wiig, & Secord, 1995), which has a series of subtests tapping a range of receptive and expressive language abilities. Table 1 also shows standard scores for a test of sentence comprehension, the Test for the Reception of Grammar (TROG; Bishop, 1983), and a test of single word comprehension, the British Picture Vocabulary Scales (BPVS; Dunn et al., 1982). The 12 children aged 12.0 and over were tested on the Test of Adolescent Word-Finding (TAWF; German, 1990), and these standard scores are also shown in Table 1. They show that even though grammatical deficits are argued to be core to the language impairment in children with G-SLI, these children also have deficits in receptive and expressive vocabulary.

We selected four groups of typically developing control children, who were attending state schools in London. These children were selected by their teachers on the basis that they were performing adequately at school, had no diagnosed special educational needs

Table 1
G-SLI participants' standard scores for a range of language assessments

	Standard scores		
	Mean	S.D.	Range
CELF-receptive	65.00	6.50	59–80
CELF-expressive	57.56	5.68	50–70
TROG	72.13	9.84	55–98
BPVS	76.88	12.94	57–87
TAWF	67.42	6.44	57–78

CELF: Clinical Evaluation of Language Fundamentals (Semel et al., 1995). TROG: Test for Reception of Grammar (Bishop, 1983). BPVS: British Picture Vocabulary Scales (Dunn, Dunn, Whetton, & Pintilie, 1982). TAWF: Test of Adolescent Word Finding (German, 1990).

and had never been referred to a Speech and Language Therapist. All the language-matched children scored within the normal range on the standardised tests of language that we administered as part of this study (the age-matched children were not tested on these). We included both a chronological age control group (CA, mean age 14.3) and a vocabulary control group (Language Age 3, LA3, mean age 8.0), as Montgomery (1998) did. The LA3 group was matched for receptive vocabulary using the BPVS, $t(25) = -0.569$, $p = 0.574$. We also had two younger control groups, LA1 and LA2, as we typically do in our studies (e.g. van der Lely & Ullman, 2001). The LA1 group (mean age 6.0) was matched to the G-SLI group for expressive morphosyntax, using the Grammatical Closure subtest of the Illinois Test of Psycholinguistic Ability (ITPA; Kirk, McCarthy, & Kirk, 1968), $t(26) = 0.749$, $p = 0.460$. The LA2 group (mean age 7.0) was matched to the G-SLI group for sentence comprehension, using the TROG, $t(26) = 0.865$, $p = 0.395$. Expressive morphosyntax and sentence comprehension matches are motivated in this particular study because half of our stimuli are inflected verbs. Verb inflection is a morphosyntactic construction, and items which measure its production and comprehension are included in the ITPA and TROG, respectively. Table 2 shows the distribution in ages of all five participant groups, while Table 3 shows the raw and standardised language scores for the G-SLI group and the three language control groups.

Table 2
Distribution of ages in participant groups

	G-SLI	LA1	LA2	LA3	CA
N	16	12	12	11	12
Age, mean (S.D.)	13.3 (2.0)	6.0 (0.5)	7.0 (0.3)	8.0 (0.5)	14.4 (1.5)

Table 3
Details of G-SLI and language-matched groups' scores on standardised language tests

			G-SLI	LA1	LA2	LA3
ITPA						
	Raw	Mean (S.D.)	**22.35 (3.74)**	**23.58 (5.12)**	26.67 (2.90)	28.27 (3.32)
		Range	**15–28**	**14–29**	21–30	22–32
	%	Mean (S.D.)	n/a[a]	47.83 (8.32)	45.50 (4.58)	42.09 (4.93)
		Range		31–55	38–53	33–47
TROG						
	Raw	Mean (S.D.)	**14.94 (1.95)**	14.08 (1.73)	**15.67 (2.57)**	16.36 (2.20)
		Range	**12–18**	11–17	**12–19**	12–19
	SS	Mean (S.D.)	72.13 (9.84)	104.58 (7.88)	109.00 (18.33)	104.91 (12.80)
		Range	55–98	91–117	90–139	86–133
BPVS						
	Raw	Mean (S.D.)	**82.56 (17.50)**	62.00 (14.45)	71.83 (8.60)	**79.00 (11.49)**
		Range	**59–114**	42–88	56–86	**56–96**
	SS	Mean (S.D.)	76.88 (12.94)	108.42 (16.87)	109.50 (7.80)	105.20 (9.66)
		Range	57–87	93–139	97–121	88–122

Group matches, on the basis of raw scores, are shown in bold. %: percentile; SS: standard score.
[a]Please note that the ITPA is not standardised for this age group.

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2.2. Stimuli

Stimuli are shown in Table 4. We chose regular verbs and manipulated frequency and past tense inflection. Frequency estimates were taken from Francis and Kucera (1982). For inflected forms, items using the full range of past tense allomorphs were chosen (e.g. /t/, *chopped*; /d/, *stirred*; /Id/, *needed*). We balanced conditions for neighbourhood size, using neighbourhood size estimates from Plaut, McClelland, Seidenberg, and Patterson (1996), because Mainela-Arnold et al. (2005) showed that SLI children are sensitive to neighbourhood size. A *t*-test revealed that high and low frequency verbs did not differ in neighbourhood size, $t(18) = 0.530$.

A series of independent samples *t*-tests revealed that there was no significant difference in frequency between the bare stem forms of the high frequency uninflected verbs and the past tense forms of the high frequency inflected verbs, $t(8) = 0.251$, $p = 0.808$. Similarly, there was no significant difference in frequency between the bare stem forms of the low frequency uninflected verbs and the past tense forms of the low frequency inflected verbs, $t(8) = 0.759$, $p = 0.470$. Pooling the high frequency conditions and comparing them to the two low frequency conditions revealed a highly significant difference, $t(18) = 5.628$, $p < 0.001$. However, pooling the two uninflected conditions and comparing them to the two inflected conditions revealed no significant difference in frequency, $t(18) = 0.580$, $p = 0.569$.

In addition, there were 34 filler items, 26 nouns and 8 adjectives, which were a mixture of inflected and uninflected words, and a mixture of one- and two-syllable words. These were included so that participants were less likely to adopt a strategy of trying to consciously give a verb as a response.

Items were recorded onto digital audiotape, digitally sampled at 44,100 Hz and edited using Protools software version 3.2 by Digidesign. The first gate was 120 ms in duration, and subsequent gates were an additional 60 ms, with a 20 ms fade after each gate. The number of possible gates ranged from 8 to 15, depending on the length of the word, with a mean of 11.6. Gated items were then recorded onto digital audiotape using Sony Digital audiotape recorder TCD-D3 and input from digital I/O adapter RM-D3K. Stimuli were presented on Sony Digital audiotape recorder TCD-D3 through headphones. Responses were recorded onto Sony PDP-64 digital audiotape using Sony Electret condenser

Table 4
Details of verb stimuli

Frequency	Inflection	*N*	Items	Mean frequency (S.D.) bare stem form	Mean frequency (S.D.) past tense form
High	No	5	call, care, help, talk, want	**229** (**84**)	153 (160)
	Yes	5	hoped, needed, passed, planned, looked	246 (130)	**167** (**126**)
Low	No	5	bake, bump, fix, trick, tug	**10** (**5**)	20 (37)
	Yes	5	chopped, pasted, ripped, stalked, stirred	5 (4)	**7** (**5**)

Mean frequency (and standard deviation) of target form is in bold.

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microphone ECM-959 and Sony Digital audiotape recorder TCD-D3. Items were randomised and presented in one fixed list.

2.3. Procedure

The experimenter (second author) gave instructions as follows: 'You are going to hear a little bit of a word. Then you are going to hear a bit more of the word. At first you can't tell what the word is. I want you to tell me what you hear. When you think you can tell what the word is, I want you to make a good guess. Remember, only good guesses. OK. Let's practice'. If required, the child was reminded to respond to each presentation during the training session. There were three training items. Each target item was presented until the child gave three correct responses or until the last gate was presented.

3. Results

3.1. Coding of results

Responses were transcribed on-line by the experimenter and then checked from the recording that was made during the session. Correct responses took into account mild and consistent articulation difficulties (e.g. /w/ for /r/ and /θ/ for /s/). Two measures were calculated:

- *Criterion* 1. First correct response ('point of isolation')
- *Criterion* 2. First of three consecutive correct responses ('point of acceptance')

This second criterion provides a measure of how robust the child's phonological representation for the target word is, by measuring how effectively competing lexical items are eliminated during the selection process. Its use here was motivated by Mainela-Arnold et al.'s finding that SLI children did not differ from their age matches with respect to the point of isolation, but did with respect to the point of acceptance.[1] Both measures were calculated as number of gates taken to reach criterion/total of gates for that word, so values were proportional values between 0 and 1. If the child did not end on the correct response or never identified the word, he or she was given a score of 1 for that item. Fig. 1 shows how the scoring worked. The groups' mean scores are shown in Table 5.

The results section is structured as follows. In Section 1 we analyse the data from the G-SLI children compared to the three language-matched control groups, and in Section 2 we compare the G-SLI and their chronological age matches. Within each section, we first present analyses according to criterion 1 (point of isolation), and secondly according to criterion 2 (point of acceptance). Data are analysed by subject (F_1) and by item (F_2) (Fig. Q3 2).

[1]An anonymous reviewer asked why we did not use a slightly different measure as our 'point of acceptance', namely the point after which the child did not vacillate any more, in case our criterion was unduly reducing the difference between the G-SLI and typical groups. When we returned to the data to recode our participants' responses in this way, no differences were noted between the two coding systems: in other words, no child changed his response once he had given three correct responses in a row.

a

	120	180	240	300	360	420	480	540	600	660	720
Child's response	puh	pay	pay	pace	pace	pace	pace	paste	pasted	pasted	pasted
Criterion 1 (point of isolation)											
Criterion 2 (point of acceptance)											

b

	120	180	240	300	360	420	480	540	600	660
Child's response	buh	bum	bump	bump	bum	bump	bump	bump		
Criterion 1 (point of isolation)										
Criterion 2 (point of acceptance)										

Fig. 1. (a) An example of a response where criterion 1 and criterion 2 are identical, for the form 'pasted'. (b) An example where criterion 1 and criterion 2 are different, for the form 'bump'.

Table 5
Responses (proportion of gates to correct response), mean (S.D.)

Frequency	Inflected	G-SLI	LA1	LA2	LA3	CA
Point of isolation						
High	No	0.590 (0.164)	0.652 (0.103)	0.676 (0.058)	0.574 (0.068)	0.517 (0.92)
	Yes	0.788 (0.060)	0.826 (0.041)	0.811 (0.045)	0.813 (0.062)	0.781 (0.072)
Low	No	0.770 (0.078)	0.860 (0.056)	0.779 (0.085)	0.786 (0.081)	0.709 (0.069)
	Yes	0.780 (0.053)	0.821 (0.048)	0.837 (0.028)	0.808 (0.055)	0.787 (0.056)
Point of acceptance						
High	No	0.662 (0.115)	0.696 (0.114)	0.695 (0.042)	0.613 (0.076)	0.579 (0.103)
	Yes	0.816 (0.031)	0.844 (0.031)	0.825 (0.038)	0.830 (0.047)	0.800 (0.047)
Low	No	0.803 (0.071)	0.871 (0.059)	0.834 (0.078)	0.795 (0.075)	0.752 (0.067)
	Yes	0.811 (0.060)	0.830 (0.044)	0.845 (0.037)	0.828 (0.032)	0.809 (0.062)

3.2. G-SLI group compared to language-matched controls

3.2.1. Criterion 1 (point of isolation)

A 4 (Group: G-SLI, LA1, LA2, LA3) $\times$ 2 (Frequency: high, low) $\times$ 2 (Inflection: inflected, uninflected) ANOVA by subjects reveals a significant third-order interaction, $F_1(3,47) = 4.26$, $p = 0.010$. None of the second-order interactions involving group are significant: group $\times$ frequency, $F_1(3,47) < 1$, and group $\times$ inflection, $F_1(3,47) = 1.27$, although the main effect of group is, $F_1(3,47) = 3.49$, $p = 0.023$. The interaction between

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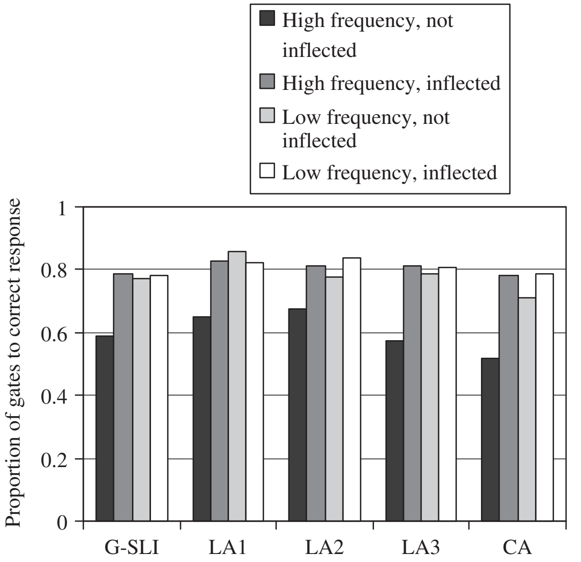

Fig. 2. 'Point of isolation' responses.

frequency and inflection is significant, $F_1(3,47) = 125.48$, $p<0.001$, and we explore this interaction first. Within high frequency verbs, inflected verbs require a higher proportion of gates than uninflected, $t(50) = 12.18$, $p<0.001$. Within low frequency verbs, there is no significant difference between inflected and uninflected verbs, $t(50) = 1.02$. The interaction arises because significantly fewer gates are required for the identification of high frequency uninflected items relative to other conditions.

The third-order interaction was investigated in a series of one-way ANOVAs by group within each condition. For low frequency inflected verbs there is a significant effect of group, $F_1(3,47) = 3.43$, $p = 0.024$. For low frequency uninflected verbs, there is likewise a significant effect of group, $F_1(3,47) = 3.75$, $p = 0.017$. Within high frequency inflected verbs and high frequency uninflected verbs there is no effect of group, $F_1(3,47) = 1.26$ and $F_1(3,47) = 2.23$, respectively.

The significant effect of group for the low frequency inflected verbs was investigated by means of planned comparisons. The LA1 and LA2 groups perform significantly worse than the G-SLI group, $F_1(1,47) = 4.80$, $p = 0.033$, and $F_1(1,47) = 9.23$, $p = 0.004$, respectively. Planned comparisons within the low frequency uninflected verbs likewise show that the LA1 group performs significantly worse than the G-SLI, LA2 and LA3 groups, $F_1(1,47) = 9.63$, $p = 0.003$, $F_1(1,47) = 6.92$, $p = 0.011$ and $F_1(1,47) = 5.56$, $p = 0.023$, respectively, but that the LA2 group does not differ from the G-SLI group.

The main effect of group was further investigated by means of planned comparisons, which show that the LA1 and LA2 groups both perform worse than the G-SLI group, $F_1(1,47) = 8.46$, $p = 0.006$ and $F_1(1,47) = 4.75$, $p = 0.034$, respectively. The LA1 group also performs worse than the LA3 group, $F_1(1,47) = 4.26$, $p = 0.044$.

The 4 (Group: G-SLI, LA1, LA2, LA3) $\times$ 2 (Frequency: high, low) $\times$ 2 (Inflection: inflected, uninflected) ANOVA repeated by items reveals no significant three-way interaction, $F_2(3,16)<1$, and no significant two-way interactions involving group, both

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$F_2(3,16)<1$. Again, the frequency × inflection interaction is significant, $F_2(1,16) = 9.078$, $p = 0.008$, but this time the effect of group is not significant, $F_2(3,16)<1$.

3.2.2. Criterion 2 (point of acceptance)

A 4 (Group: G-SLI, LA1, LA2, LA3) × 2 (Frequency: high, low) × 2 (Inflection: inflected, uninflected) ANOVA carried out by subjects reveals that the third-order interaction is not significant, (3,47) = 1.10, and nor are second-order interactions involving group: group × frequency, $F_1(3,47)<1$ and group × inflection, $F_1(3,47) = 2.01$, although Q4 there is a significant main effect of group, $F_1(3,47) = 3.35$, $p = 0.027$ (Fig. 3).

The interaction between frequency and inflection is significant, $F_1(1,47) = 105.20$, $p<0.001$. For high frequency verbs, inflected verbs require a greater proportion of gates than uninflected, $t(50) = 11.39$, $p<0.001$. For low frequency verbs, there is no significant difference between inflected and uninflected items, $t(50)<1$. The interaction arises because of particularly effective identification of high frequency uninflected items.

Planned comparisons following up the main effect of group reveal that the LA1 group performs significantly worse than the G-SLI group, $F_1(1,47) = 5.96$, $p = 0.018$, and worse than the LA3 group, $F_1(1,47) = 6.77$, $p = 0.012$.

A 4 (Group: G-SLI, LA1, LA2, LA3) × 2 (Frequency: high, low) × 2 (Inflection: inflected, uninflected) ANOVA carried out by items reveals a similar pattern of results. The third-order interaction is not significant, $F_2(3,16) = 1.11$, and nor are second-order interactions involving group: group × frequency, $F_2(3,16)<1$ and group × inflection, $F_2(3,16)<1$. The interaction between frequency and inflection is significant, $F_2(1,16) = 5.907$, $p = 0.027$, but the effect of group is not, $F_2(1,8)<1$.

Importantly, it is not the G-SLI children who contribute to the third-order interaction in the by subjects analyses, nor to the main effect of group. Children with G-SLI do not require a higher proportion of gates than the other groups for any of the conditions. In

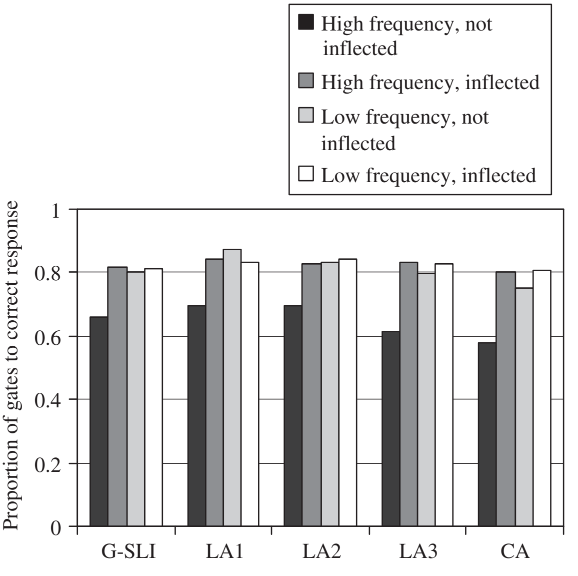

Fig. 3. 'Point of acceptance' responses.

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fact, they do not differ from their vocabulary controls and perform significantly better than their sentence comprehension (by criterion 1) and morphosyntax (by criteria 1 and 2) matched controls.

3.3. G-SLI group compared to age-matched controls

3.3.1. Criterion 1 (point of isolation)

A 2 (Group: G-SLI, CA) × 2 (Frequency: high, low) × 2 (Inflection: inflected, uninflected) ANOVA by subjects reveals that the third-order interaction is not significant, $F_1(1,26)<1$. Of the two-way interactions involving group, the group × frequency interaction is not significant, $F_1(1,26)<1$, but the group × inflection interaction is *marginally* significant, $F_1(1,26) = 4.04$, $p = 0.055$. The main effect of group is not significant, $F(1,26) = 1.97$.

The interaction between frequency and inflection is significant, $F_1(1,26) = 69.15$, $p<0.001$. *t*-tests reveal that amongst the uninflected verbs, high frequency items require a significantly lower proportion of gates than the low frequency items, $t(27) = -9.11$, $p<0.001$. Amongst the inflected verbs, however, there is no significant difference between high and low frequency items, $t(27)<1$.

Probing the marginal group × inflection interaction more closely, we find that there is no difference between the groups on the inflected verbs, $t(26)<1$, whereas there is a marginally significant group difference for the uninflected verbs, with the GSLI children requiring a higher proportion of gates than the CA matched children, $t(26) = 1.83$, $p = 0.059$.

In a 2 (Group: G-SLI, CA) × 2 (Frequency: high, low) × 2 (Inflection: inflected, uninflected) ANOVA by items, the only significant interaction is between frequency and inflection, $(1,8) = 6.241$, $p = 0.037$.

3.3.2. Criterion 2 (point of acceptance)

A 2 (Group: G-SLI, CA) × 2 (Frequency: high, low) × 2 (Inflection: inflected, uninflected) ANOVA by subjects reveals that the third-order interaction is not significant, $F_1(1,26)<1$. Although the group × frequency interaction is not significant, $F_1(1,26) = <1$, once again the group × inflection interaction is *marginally* significant, $F_1(1,26) = 3.96$, $p = 0.057$. This time the effect of group is very close to significance, $F_1(1,26) = 4.18$, $p = 0.051$, with better performance by the CA controls.

The interaction between frequency and inflection is highly significant, $F_1(1,26) = 48.98$, $p<0.001$. As before, *t*-tests reveal that for high frequency verbs, inflected verbs require a higher proportion of gates than uninflected, $t(27) = 8.87$, $p<0.001$, whereas for low frequency verbs, there is no significant difference between inflected and uninflected verbs.

Following up the group × frequency interaction reveals that while there is no difference between the groups for inflected forms, $t(26) = 0.608$, for uninflected forms this difference is significant, $t(26) = 2.30$, $p = 0.030$.

In a by items analysis, the 2 (Group: G-SLI, CA) × 2 (Frequency: high, low) × 2 (Inflection: inflected, uninflected) ANOVA reveals only one significant interaction, between frequency and inflection, $F_2(1,8) = 5.397$, $p = 0.049$.

These results indicate that the G-SLI children are no slower overall in their recognition of gated verbs compared to the CA matched controls by criterion 1. In a by subjects analysis, the only conditions in which they have a tendency to be slower (by criterion 1) or

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are significantly slower (by criterion 2) are the uninflected conditions, and not the inflected conditions.

4. Discussion

We scored responses according to two criteria: (1) proportion of gates to the first correct response (point of isolation), (2) proportion of gates to the first of three consistent correct responses (point of acceptance). The G-SLI group did not differ from their language matches by either criterion, and did not perform worse than their age-matched controls with respect to the point of isolation. They performed worse than their age-matched controls only with respect to the point of acceptance criterion, and only for the uninflected verbs. These results indicate that the two groups activate the correct word at the same point in the word, but that the G-SLI group takes longer to reach a consistent response by ruling out alternative lexical items in the target's cohort. This last result is consistent with Mainela-Arnold et al.'s (2005) finding that SLI children waver between multiple word candidates for longer. We found a significant interaction between frequency and inflection, with high frequency uninflected verbs requiring a lower proportion of gates for isolation and acceptance compared to other conditions. Importantly, G-SLI children show the same effects of frequency and inflection as their age and vocabulary controls. Any interactions involving group arise from different behaviour by the LA1 controls and, less frequently, the LA2 controls.

For low frequency items, all groups require a higher proportion of gates, and this is not disproportionately so for the G-SLI children: G-SLI children do not perform particularly poorly on low frequency verbs. This replicates previous findings by Mainela-Arnold et al. (2005), but is contrary to those of Dollaghan (1998). Dollaghan proposed that her group of SLI children had weaker representations of low frequency words compared to typically developing children, but our results do not support that claim for the G-SLI subgroup. However, her methodology differed from ours in that her low frequency words were new words that were taught under experimental conditions (a fast-mapping task) just prior to the gating study in the same experimental session. Dollaghan used this method precisely because frequency counts of the type we used do not control for individual children's exposure to vocabulary, which is arguably reduced for SLI children. Dollaghan's method ensured that all children had exactly the same number of exposures to the unfamiliar words prior to participating in the gating task. In our study, by using words that were low in frequency but presumably still familiar, the G-SLI children plausibly had encountered them often enough to have built up good phonological representations, and phonological representations that were stronger than those of newly learnt words.

There is a further explanation for Dollaghan's results: semantic, and not just phonological, problems impact on SLI children's word-learning. For example, Ellis Weismer and Hesketh (1998) conducted a word-learning task and found that children with SLI mislabelled objects more often than controls, i.e. they recalled the phonological form of a particular novel word but associated it with the wrong object. The authors interpreted errors of this type as implicating additional difficulties with deriving the semantic properties of a word and/or relating the referent for the semantic properties via lexical access, i.e. difficulties that go beyond phonological deficits. If Dollaghan had used vocabulary matches in her study, we might have been able to pinpoint more precisely why the results of her and our studies differ.

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Although G-SLI children, like other children with SLI, have severe problems with past tense inflection, in this study they do not require a higher proportion of gates than their typically developing controls before recognising inflected verbs. Importantly, they do not perform worse than their age-matched controls on inflected verbs, and are actually better than their sentence comprehension and morphology matched controls on low frequency inflected verbs by the criterion of first correct response. It has been proposed that poor speech processing causes SLI children's morphological impairments, but this is not supported by our data. Our results indicate that G-SLI children's acoustic-phonetic processing is precise enough to support the recognition of inflected forms.

There is a notable contrast here between G-SLI children's ability to retrieve an inflected form from the lexicon in a single word context such as this gating task, and their considerable impairment in producing a past tense form in a sentence context, for example in spontaneous speech and in elicitation tasks (van der Lely, 1998; van der Lely & Ullman, 2001). This contrast indicates that the deficit lies not in the phonological representation of the inflected form itself, but rather in the processes that retrieve that form in the relevant morphosyntactic context.[2]

This study therefore adds to the substantial body of work which seeks to provide a detailed profile of the language impairment in G-SLI. On current evidence, these children's core deficits are restricted to those grammatical constructions in syntax, inflectional morphology and phonology that rely on hierarchical structure, and cannot be ascribed to lower level auditory processing deficits (see van der Lely, 2005, for a review). These results do not conflict with models such as Joanisse (in press), that see the past tense deficit in SLI resulting not so much from the child misperceiving the suffix, as from having weak representations of features such as voice and place. Such weak featural representations then compromise the child's ability to maintain phonological forms in working memory, to analyse relationships amongst different morphological forms of the same word, such as *walk* and *walked*, and then generalise these patterns to new words. However, our results do conflict with accounts that claim that children with SLI have problems actually perceiving word suffixes correctly (Leonard et al., 1992; Tallal & Piercy, 1974).

Importantly, we are not claiming that phonological representations in G-SLI are unimpaired. After all, for uninflected verbs the G-SLI group performed significantly worse than age-matched controls on the criterion of 'point of acceptance' for uninflected verbs, indicating that they are less consistent in their responses for these items. G-SLI children need to be presented with a larger proportion of a word before they can rule out competitors in that word's cohort, presumably due to phonological representations that are less clearly specified compared to their controls.

Furthermore, our work testing non-word repetition abilities indicates that structural aspects of phonology, such as complex syllable and metrical structure, cause a decrease in repetition accuracy, alongside the effects of syllable number (Gallon et al., 2007; Marshall, 2006; Marshall et al., 2003). We have also shown that phonological complexity affects regular past tense formation in these children—they are less likely to use the suffix if doing so produces a cluster (Marshall & van der Lely, 2007b). However, the results of the gating study presented here suggest that a perceptual deficit, predicted to impact particularly strongly on the perception of the past tense suffix, does not in fact affect the recognition of inflected forms.

[2]We thank an anonymous reviewer for encouraging us to discuss this point.

In conclusion, although children with G-SLI have severe impairments in inflectional morphology, this study provides little support for the hypothesis that G-SLI children have difficulty recognising the phonetic-acoustic form of inflected verbs, and that such a difficulty is the cause of their inflectional impairment. Our results add instead to the weight of evidence suggesting that at least some forms of SLI do not have their roots in the poor perception of speech, and are consistent with theories that the locus of the deficit is in the grammatical system itself.

Q5 Uncited references

Joanisse (2004), van der Lely and Stollwerck (1996).

Acknowledgements

We are most grateful to the children, their parents, and the staff at Moor House School (Hurst Green), Dawn House School (Rainworth), The Oratory School (London) and St. Georges School (London). We thank Stephen Long for his help with the statistical analysis. We also thank three anonymous reviewers, whose thought-provoking comments on earlier versions of this manuscript contributed enormously to its clarity. This work was supported by Wellcome Trust grants (059876 and 063713) and an ESRC grant (RES-000-23-0575) awarded to HvdL.

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