The impact of phonological complexity on past tense inflection in children with Grammatical-SLI

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Abstract

English-speaking children with Specific Language Impairment (SLI) variably produce inflected and bare stem forms in obligatory past tense contexts. Researchers have not reached consensus as to whether the underlying deficit is morphosyntactic or morphophonological in nature. The Computational Grammatical Complexity (CGC) Hypothesis takes a different tack: it hypothesizes that for children with a particular form of SLI, Grammatical-SLI, the deficit is in representing linguistic structural complexity in at least three components of the computational grammatical system—syntax, morphology and phonology. Deficits in all these components are predicted to impact on regular past tense formation. The impact of syntactic and morphological complexity on G-SLI children's realization of tense has been tested previously. Here we complete the picture by considering phonological effects on their production of regular past tense inflection. Using a past tense elicitation task where we manipulate the phonological complexity of the inflected verb end, we show that, as predicted, verb-end phonological complexity impacts on suffixation: G-SLI children are less likely to suffix stems when the inflected form ends in a consonant cluster. Typically developing controls show no such effect. The results of this study highlight the need to consider the independent contributions of language components to impaired and normal performance.

Keywords: *Grammatical-specific language impairment, past tense inflection, phonological complexity, computational grammatical complexity hypothesis, consonant clusters.*

Introduction

Past tense morphology in SLI

Children with Specific Language Impairment (SLI) have significantly impaired language acquisition in the absence of any obvious language-independent cause, such as hearing loss, low non-verbal IQ, motor difficulties or neurological damage (see Leonard, 1998, for a review). Within the SLI population as a whole, deficits have been diagnosed in syntax, morphology, phonology and the lexicon (Leonard, 1998). The language deficit is not uniform, however: it is well-established that English-speaking children with SLI have difficulties in marking tense and agreement that extend above and beyond their overall language delay. This deficit manifests itself in the production of both inflected and bare stem forms in contexts that require the verb to be inflected (Loeb & Leonard, 1991; Oetting & Horohov, 1997; Rice, Wexler & Cleave, 1995; Ullman & Gopnik, 1999). Indeed, the omission of past tense *-ed*, third person singular *-s*, *be* and *do* is

considered to be a clinical marker for SLI (Rice & Wexler, 1996; Rice et al., 1995). Importantly, the omission of these morphemes in obligatory contexts is optional, but where they are supplied, they are generally supplied correctly. Although these findings have been replicated in many studies (Conti-Ramsden & Windfuhr, 2002; Loeb & Leonard, 1991; Norbury, Bishop & Briscoe, 2001; Oetting & Horohov, 1997; Ullman & Gopnik, 1999; van der Lely & Ullman, 2001), there is little consensus as to their underlying cause.

Several researchers see the deficit as being linguistic, and principally morphosyntactic, in nature (Clahsen, 1989; Clahsen, Bartke & Gollner, 1997; Gopnik, 1999; Rice & Wexler, 1996; Ullman & Gopnik, 1999; van der Lely & Ullman, 2001). For example, Rice and Wexler's Extended Optional Infinitive (EOI) Hypothesis and its more recent extension, the Unique Checking Constraint (UCC) Hypothesis (Rice & Wexler, 1996; Rice et al., 1995; Rice, Wexler & Hershberger, 1998; Rice, Wexler & Redmond, 1999; Wexler, 1998), claim that syntactic features which mark tense and agreement inflection

develop later than normal. SLI children experience a prolonged period in which they are not able to obligatorily mark tense and agreement; during this time, both inflected and uninflected stems are acceptable forms in their grammar. The term “extended” is used because an optional infinitive stage is also characteristic of younger, typically developing children. However, while typically developing children cease to use optional infinitives at about age 3, children with SLI still produce them for many years beyond that age.

The Computational Grammatical Complexity (CGC) Hypothesis hypothesizes that for children with a particular form of SLI, Grammatical-SLI, the deficit is in representing linguistic structural complexity in at least three components of the computational grammatical system—syntax, morphology and phonology (Marshall, 2004, 2006; van der Lely, 2005). Deficits in all these components are predicted to impact on regular past tense formation. We return to the CGC Hypothesis and its predictions for past tense marking in more detail in the next section.

The claims of a morphosyntactic deficit in SLI have been criticized by researchers who propose it is the phonological properties of regular past tense forms that place the suffix at risk of omission, not an impairment in a suffixation rule per se (Bernhardt & Stemberger, 1998; Joanisse & Seidenberg, 1998, 2003; Leonard, 1989; McClelland & Patterson, 2002). There is evidence that some SLI children have difficulty processing rapidly-presented sequential information, and this is hypothesized to affect the processing of acoustic stimuli (McClelland & Patterson, 2002; Tallal & Piercy, 1973a, b). This deficit is predicted to impact in particular on the acoustically non-salient /t/ and /d/ inflections, resulting in poor phonological representations of past tense forms. In Joanisse’s (2004) model, he stresses the phonological similarity between the stem and past tense forms of regular verbs, e.g., *walk* and *walked*. He proposes that children with SLI have difficulties in translating the acoustic forms of words into a phonological code necessary for learning the past tense.

The Surface Hypothesis (Leonard, 1989, 1998) claims that SLI children have slow and limited processing abilities. These slow processing abilities are hypothesized to affect the realization of English inflection because it is frequently represented by suffixes that have low perceptual salience, e.g., past tense /t/ and /d/, plural and third person /s/ and /z/. For a cognitive system that is already under strain due to a deficit in processing ability, the lack of perceptual saliency of these morphemes makes them more difficult to process than would typically be the case. This in turn leads to difficulty in setting up morphological paradigms (in the sense of Pinker, 1984). Of critical importance to the Surface Hypothesis is the interaction between morphology and phonology. It is not that the perception of, say,

word-final /t/ per se that is difficult for SLI children. Rather, it is because their limited processing ability is taxed when this sound plays a morphological role that there are repercussions for a word with a past tense inflection, such as *missed*. In this case they have to relate *missed* to *miss*, hypothesize that the /t/ is a morpheme in its own right and place it in the correct morphological paradigm. A monomorphemic word such as *mist*, in contrast, does not pose these difficulties.

Importantly, Joanisse (2004), Leonard (1998) and other researchers (Bernhardt and Stemberger, 1998; Joanisse & Seidenberg, 1998; Tallal & Piercy, 1973a, b), propose that inflectional deficits arise from difficulties with perception and slow processing that affect morphosyntax, rather than from a deficit in morphosyntax itself. However, given that a significant proportion of children with SLI do not have perceptual deficits (Bishop, Carlyon, Deeks, & Bishop, 1999; van der Lely, Rosen, & Adlard, 2004), should we expect all children with SLI to manifest the same type of past tense deficit?

Subgroups of SLI and the G-SLI population

Heterogeneity of language deficits within the SLI population has been acknowledged (see discussion in Bishop, 2003; Leonard, 1998; van der Lely, 2003), but is not accommodated within most current theories. Moreover, given the robust findings of past tense deficits in the SLI population, the significance of heterogeneity with regards to past tense inflection is not well understood.

The existence of subgroups of SLI children whose members share a common profile of linguistic strengths and weaknesses has been proposed, but is controversial (Aram, Morris & Hall, 1993; Aram & Nation, 1975; Rapin & Allen, 1983). It is of course possible that what appear to be different subgroups are just variable manifestations of a common language disorder (Bishop, 1997). On the other hand, van der Lely and her colleagues have identified a subgroup of children that they classify as having Grammatical (G)-SLI. G-SLI children’s language difficulties are claimed to be relatively homogeneous and to encompass the core aspects of grammar—syntax, morphology and phonology, whereas the lexicon, including derivational morphology, is relatively spared, and pragmatics and articulation are unaffected (Gallon, Harris, & van der Lely, under revision; Marshall, Harris & van der Lely, 2003; Marshall & van der Lely, 2007; van der Lely, 1997a, b, 1998, 2005; van der Lely & Battell, 2003; van der Lely, Rosen, & McClelland, 1998; van der Lely & Stollwerck, 1997).

Like other children with SLI, those with G-SLI have difficulty marking tense. Van der Lely and Ullman investigated regular and irregular past tense formation in a group of twelve children with G-SLI, aged 9;03–12;10, and in three groups of typically

developing children matched on standardized measures of morphology and vocabulary (van der Lely & Ullman, 2001). They found that the G-SLI and language-matched controls showed quantitatively and qualitatively different patterns of performance. The G-SLI children's production of regular past tense forms was significantly lower than that of all three control groups. Their performance on irregular past tense verbs was lower than that of the two groups matched for vocabulary level but not significantly different from the group matched for morphology. These findings suggested that the difficulties G-SLI children face with regular inflection could not be solely accounted for by their language age. Two patterns in the data were crucial to van der Lely and Ullman's interpretation of those data:

- the control children showed a significant advantage for regular over irregular verbs, whereas the G-SLI children did not;
- the G-SLI children showed a consistent frequency effect for both regular and irregular verbs, whereas the controls did so only for irregular verbs.

Van der Lely and Ullman claimed that G-SLI children preferentially retrieve stored regular forms from the lexicon, whereas typically developing children compose regular forms *de novo* from the verb stem and past tense morpheme. In other words, G-SLI children have a deficit creating morphologically complex forms, which results from them being inconsistent in their use of the regular suffixation rule, and having to rely instead on the storage of forms that are already inflected.

In a test of van der Lely and Ullman's hypothesis, Marshall and van der Lely compared G-SLI children's production of two types of regular verbs that differ in the phonotactics of the cluster formed at the inflected verb end (Marshall & van der Lely, 2006). Monomorphemically legal verbs end in a cluster that is also found in monomorphemic (i.e., uninflected) words (e.g., *missed/mist*; *rolled/gold*), whereas monomorphemically illegal verbs end in a cluster that is not found in monomorphemic words (e.g., *hugged*, *robbed*, *rushed*). Marshall and van der Lely reasoned that if G-SLI children store past tense forms, then cluster frequency should affect inflectional accuracy (independently of verb frequency), and verbs ending in a legal cluster should be more readily inflected than those with an illegal cluster, as legal clusters are considerably more frequent than illegal clusters (this is because they occur in both monomorphemic and inflected forms, whereas illegal clusters occur only in inflected forms). This was indeed the case—a reanalysis of van der Lely and Ullman's data, and data from a new group of G-SLI children, showed that G-SLI children found it easier to inflect verbs that form legal rather than illegal clusters, whereas

typically developing children showed no effect of phonotactics (Marshall & van der Lely, 2006). Hence the data supported the hypothesis that G-SLI children store regular past tense forms. A further explanation is that G-SLI children create new past tense forms by analogy to forms that they have already stored, and that forms that contain legal clusters were produced more readily because legal clusters are more frequent. In either case, G-SLI children showed a qualitatively different pattern of performance compared to their language matched controls.

However, the past tense deficit is not solely a morphological deficit—it also has a syntactic component (van der Lely, 2005). G-SLI children inconsistently manipulate core aspects of syntax such as the assignment of thematic roles to noun phrases, the assignment of coreference to pronouns and anaphors when only syntactic cues are available, and the production of questions requiring Wh-movement (van der Lely, 2005). In order to explain this deficit in syntax, van der Lely claims that G-SLI children have difficulty in setting up syntactic dependencies that depend on "Movement" (Chomsky, 1995). The realization of tense and agreement features requires a syntactic dependency between the verb and the inflection node. If this dependency is not created, then tense and agreement features cannot be checked, and therefore not spelt out on the verb (Chomsky, 2000, 2001; Davies, 2001). This deficit in syntactic dependencies can account for the G-SLI group's poor performance on both regular and irregular verbs in the past tense task, and the deficit in producing morphologically complex forms can explain why the deficit is worse for regulars than irregulars relative to typically developing children. In other words, individuals with G-SLI have a dual deficit—in syntax and in morphology.

Those researchers who favour an auditory processing/phonological deficit underlying SLI (e.g., Bernhardt & Stemberger, 1998; Joanisse & Seidenberg, 2003) claim that van der Lely and Ullman's past tense data, and those of other researchers, can be explained as follows: it is the phonological properties of regular past tense forms that place the suffix at risk of omission, and not an impairment in a suffixation rule per se.

The problem with this view, at least for the G-SLI subgroup, is that G-SLI children have no consistent auditory deficit, and their performance on tasks involving auditory discrimination does not correlate with phonological and other language abilities. Even more troubling is the finding that several control children, who by definition have normal language skills, performed poorly on the auditory tasks (van der Lely et al., 2004). This indicates that auditory processing difficulties are neither necessary nor sufficient to cause G-SLI (Bishop et al., 1999). This of course does not rule out the possibility that G-SLI

children had auditory processing deficits at some earlier stage of development, but that particular hypothesis can only be tested through longitudinal studies, which have yet to be carried out.

Meanwhile, recent work has shown that despite a lack of an observable auditory deficit, certain aspects of phonological structure do cause difficulty for children with G-SLI. Children with G-SLI have clear and fluent speech, and are intelligible for known words. Their phonological deficit manifests as a difficulty with forms that are complex at the syllable and foot levels of the prosodic hierarchy (Gallon et al., under revision; Marshall et al., 2003). In a non-word repetition task, G-SLI children simplify consonant clusters in word-initial, word-medial and word-final positions, while the presence of unfooted syllables causes syllabic simplifications and segmental changes elsewhere in the word (Marshall, 2004; Marshall, Ebbels, Harris, & van der Lely, 2002).

Rather than treating the syntactic, morphological and phonological deficits as separate impairments, they are unified in a model that has been proposed to account for the full range of language deficits found in G-SLI children: the Computational Grammatical Complexity (CGC) Hypothesis (Marshall, 2004, 2006; van der Lely, 2005). We use the terms “computational” and “grammatical” because the core computational components of grammar (syntax, morphology and phonology) are affected, and “complexity” because the most parsimonious explanation is that the deficit in each component of grammar lies in the formation of complex structural representations. In particular, the construction of hierarchically organized structures—such as those required for syntactic dependencies that require movement (e.g., between a *wh*-word and its trace), for the creation of inflectionally suffixed forms, and for the construction of complex syllable structure—is problematic for these children (see van der Lely, 2005, for a more detailed exposition).

The CGC Hypothesis makes a prediction which we test in this paper—because phonological complexity is a feature of regular past tense formation in English, we would expect G-SLI children to find verbs with phonologically complex endings harder to inflect than verbs which are phonologically simple (van der Lely, 2005). In the next section we therefore discuss an aspect of phonological complexity that is involved in regular past tense forms—consonant clusters—and how this complexity impacts on past tense inflection in SLI.

The phonology of past tense forms and its effects in SLI

Irregular past tense forms tend not to contain clusters (e.g., *took*, *swam*, *got*, *stood*) but if they do (e.g., *slept*, *built*, *spent*, *lost*) then those clusters are from a restricted set, in that they have to also occur in monomorphemic words (cf. *accept*, *stilt*, *tent*, *frost*)

and they can contain no more than two consonants. Some regularly inflected forms, however, contain clusters that either can or can not occur in monomorphemic English words (e.g., the cluster at the end of *hugged* has no monomorphemic equivalent). In addition, a few regularly inflected forms contain clusters with three consonants, e.g., *danced* and *jumped*, whereas irregular forms do not contain such large clusters.

Interactions between syllable structure and morphology in typical development have been studied by several authors. A child who is unable to produce word final consonants or clusters is not expected to produce them in morphologically complex words. In support of this prediction, Stemberger and Bernhardt (1997) reported a child who reduced clusters in both monomorphemic and suffixed words, e.g., the /ks/ in *fox* and *rocks* is reduced to /k/. However, the pattern was not always straightforward. Stemberger and Bernhardt reported a different child who produced word-final clusters only in *suffixed* forms. They also reported data from a child who reduced monomorphemic clusters differently to clusters in suffixed forms. Therefore, the way in which children treated complex structures in monomorphemic forms did not necessarily match how they treat them in suffixed forms. Song and Demuth (2005) revealed that frequency is an important factor in children’s success with grammatical morphemes—both the input frequency of the grammatical morpheme itself (e.g., plural versus third person singular) and the frequency of the phonological structure in which that morpheme is encountered (single consonant versus consonant cluster). Kirk and Demuth (2005) showed that the segmental content of final clusters is a further factor in accurate realization: for example, in their study children acquired stop + /s/ clusters before /s/ + stop clusters.

It is unclear whether verb-end phonology affects inflectional morphology to a greater extent in SLI children compared to younger language-matched peers. One study showed that 6-year-old SLI children and their 4-year-old language-matched controls found past tense forms without a cluster easier to inflect than those with a cluster, but that forms with a cluster were not disproportionately more difficult for the SLI children (Oetting & Horohov, 1997). Another study similarly showed that word-end phonology affects both SLI children (aged 3;7 to 5;9) and their language-matched controls (aged 2;5 to 3;3) (Bortolini & Leonard, 2000). The two groups showed a correlation between final cluster reduction in monomorphemic words and the omission of consonantal inflections (not only past tense, but also plural, genitive and third person –s), but the SLI group produced considerably more final cluster reduction on monomorphemic words than their controls. However, this study did not directly compare inflection rates where the past tense form has a cluster and forms where it does not.

A third study revealed that phonological complexity of the verb stem, as indexed by the presence of a cluster at the onset, a cluster at the end, or by clusters at both the beginning and the end, had an effect on past tense inflectional accuracy in both children with SLI aged 7;2–13;0 and their language matched controls (Norbury et al., 2001).

As for the G-SLI group, van der Lely and Ullman's (2001) study did not investigate the impact of phonology. However, in a case study of one particular G-SLI boy, AZ, van der Lely (1997b) noted that the only verbs for which AZ produced inflection in van der Lely and Ullman's elicitation task were *mar* and *stir*; those past tense forms, *marred* and *stirred*, which do not end in a cluster in this child's dialect of English.

What is clear is that the relationship between phonology and morphology merits being studied in a systematic way. One approach would be to choose verb stimuli that differ according to verb-end complexity, and investigate whether SLI children are disproportionately affected compared to their controls, i.e., whether there is an interaction between group and complexity. This is the method that we use in the study reported here, with a group of children with G-SLI.

Method

Participants

Three groups of children participated in this experiment—one group of G-SLI children and two groups of typically developing children. 14 G-SLI participants (age range 9;09–16;03, mean age 12;03) were selected on the basis of a persistent deficit in grammatical production and comprehension, as revealed by both standardized language tests and tests designed specifically to target the difficulty with complex syntactic structures that characterizes this group. The precise selection criteria for the G-SLI subgroup are well-documented but for ease of reference we will discuss them briefly here (van der Lely, 1997a, b, 1998; van der Lely et al., 1998; van der Lely & Stollwerck, 1997). Note that this group of children are not the same as those who participated in the studies listed above, but are the same as those who participated in Marshall's (2004) and Marshall and van der Lely's (2006) studies. They all had a diagnosis of SLI from a qualified speech and language therapist, fell below 1.5 standard deviation on at least two standardized tests of language, and were receiving speech and language therapy either in special language schools or in language units in mainstream schools. They were aged 9;00 years and over, and had non-verbal IQs in the normal range (i.e., 85 and above, as measured by the *Raven's Progressive Matrices* (Raven, 1998) and/or the block design subtest of the *British Ability Scales* (Elliott, 1996)). Articulation of known words (i.e., words

established in the child's vocabulary) was clear and consistent, by speech and language therapist report.

To be included in the G-SLI group, the children had to be significantly impaired in aspects of grammar that are thought to be core to the computational grammatical system. Specifically, they had to evince more than 20% errors on an expressive test of subject-verb agreement and tense marking (the Verb Agreement and Tense Test, van der Lely, 2000), a test of assigning thematic roles in reversible sentences (the Test of Active and Passive Sentences, van der Lely, 1996) and a test of assigning reference to pronouns and reflexives (the Advanced Syntactic Test of Pronominal Reference, van der Lely, 1997c). See Appendix 1 for details of individual participants.

Twenty-eight typically developing children also participated; 14 were matched on raw score (± 1) to individual G-SLI children on a test of sentence comprehension, the *Test for Reception of Grammar* (Bishop, 1993), and 14 were individually matched on raw score (± 3) on the *British Picture Vocabulary Scales* (Dunn, Dunn, Whetton, & Burley, 1997). They were then divided into two groups according to age, in order to give a picture of typical development. The Typically Developing 1 (TD1) control group were aged 4;06–7;05, with a mean age of 6;00, and the Typically Developing 2 (TD2) control group were aged 7;06–12;00, with a mean age of 9;06. See Table I for details of the participant groups. The dialect of all participants was Standard British English.

Verb stimuli

Three conditions of verbs were selected, which varied according to the complexity of their past tense form. The characteristics of each condition with regards to verb-end complexity are presented in Table II, and the full list of verbs can be found in Appendix 2.

We matched verbs on the basis of two frequency counts: the British English COBUILD corpus of the University of Birmingham, by the Centre for Lexical Information (CELEX) at the University of Nijmegen

Table I. Participant details.

Measure			G-SLI (N = 14)	TD1 controls (N = 14)	TD2 controls (N = 14)
Age		Mean	12;03	6;00	9;06
		(SD)	(1;11)	(0;10)	(1;02)
TROG	Raw score	Mean	12.86	10.79	16.43
		(SD)	(3.51)	(2.78)	(1.87)
	z-score	Mean	−1.67	−.14	.12
		(SD)	(.61)	(.63)	(.89)
BPVS	Raw score	Mean	79.93	60.00	94.12
		(SD)	(20.11)	(12.90)	(12.80)
	z-score	Mean	−1.54	.28	.28
		(SD)	(.76)	(.63)	(.50)

Note: TROG: Test for Reception of Grammar. BPVS: British Picture Vocabulary Scales.

Table II. Phonological and mean frequency characteristics of each condition.

Condition*	Consonants at verb end	Example	COBUILD frequency		CHILDES frequency	
			Lemma Mean (SD)	Past Mean (SD)	Lemma Mean (SD)	Past Mean (SD)
V-D (N=8)	1	<i>paid</i>	5.76 (1.53)	3.99 (1.68)	4.53 (2.08)	2.34 (1.73)
VC-D (N=16)	2	<i>hugged</i>	5.44 (.90)	3.76 (1.00)	4.70 (.92)	2.81 (.80)
VCC-D (N=8)	3	<i>danced</i>	4.86 (.93)	2.97 (.88)	4.25 (2.04)	1.68 (1.27)

*The reader will note that there are twice as many items in the VC-D condition as in the V-D and VCC-D conditions. This is because in an earlier experiment, Marshall and van der Lely (2006) compared performance on two different types of VC-D verbs—those ending in a phonotactically legal cluster, e.g., *yelled*, and those ending in a phonotactically illegal cluster, e.g., *hugged*.

(Baayen, Piepenbrock & van Rijn, 1993), and the Parental Frequency count from the CHILDES database (MacWhinney, 2000). The former is calculated principally from written sources and contains 17.9 million tokens. The Parental Frequency count from CHILDES comes from child-directed speech or speech heard by children and contains 2.6 million tokens. The latter might seem a better measure of children's familiarity with individual verbs. However, van der Lely and Ullman (2001) carried out a stem familiarity task which showed a very high and significant correlation between the COBUILD frequency counts and children's familiarity ratings, indicating that the COBUILD frequencies are indeed an appropriate estimate for these children.

Individual verb frequencies were augmented by 1 and ln-transformed. For the COBUILD frequency count, one way ANOVAS showed no significant differences between conditions for either lemma frequency, $F(2,31) = 1.421$, $p = .258$, or past tense frequency, $F(2,31) = 1.735$, $p = .194$. For the CHILDES parental frequency count, one-way ANOVAs likewise revealed no significant differences between conditions for either lemma frequency, $F(2,31) = .217$, $p = .806$, or past tense frequency, $F(2,31) = 2.389$, $p = .110$.

Procedure

The procedure was that used by Marshall and van der Lely (2006), and based on van der Lely and Ullman (2001). The lead in for the task presented both the past tense and bare stem form. *Last week Kipper robbed a post office. Everyday I rob a post office. Yesterday I . . . . .* Hence the lead in primed the syntactic form of the past tense, as did the inclusion of only regular stimuli. A further modification to van der Lely and Ullman's task was that none of our verb stimuli had onset clusters, so that phonological complexity occurred only at the verb end. Finally, all verbs were followed by a vowel-initial word in the stimulus sentence, because word-final /t/ and /d/ are more likely to be deleted in normal speech when the next word begins with a consonant (Guy, 1991). We reasoned that constructing stimulus sentences so that each verb was followed by a vowel-initial word would reduce

the likelihood of /t/ and /d/ being deleted for phonological rather than morphological reasons.

The experimenter introduced the child to two toy dogs. One of the dogs, Kipper, was likely to be familiar to the child through the popular children's books and television programmes. The experimenter reminded/told the child that Kipper is a very adventurous dog who does all sorts of exciting things. The second dog, who the child didn't know, was called Bean Dog. The experimenter told the child that Bean Dog is one of Kipper's best friends, but that he gets very jealous of Kipper and all the adventures that Kipper has. The experimenter explained that Kipper had been busy doing lots of things recently. Bean Dog was jealous and wanted to tell everyone that he had been doing them too. The experimenter asked the child to help her to be the voice of Bean Dog and tell everyone the things that he had been doing. There were four practice items using irregular verbs, which children were given feedback on, and 32 stimulus sentences, listed in Appendix 3. One pseudo-randomized list was created for all participants. Responses were recorded onto a Sony Digital Audio Tape-recorder TCD-D8 using an Audio-Technica microphone ATR20. Responses were transcribed live by the experimenter (first author) and subsequently checked from the audio-tape.

Coding of responses

Responses were coded as follows:

- Correct e.g., *hop* → *hopped*
- Bare stem e.g., *rob* → *rob*
- Stem-final consonant deletion e.g., *milk* → *milt*
- Other responses e.g., *wash* → *washing*;
judge → *jumped*

Predictions

We hypothesized that G-SLI children would find the phonological complexity of the inflected verb-end, as realized by the presence versus absence of a cluster, and the size of the cluster, problematic. We predicted that this feature of regular past tense forms would cause more difficulty for the G-SLI group than for groups of typically developing, language-matched

peers. More specifically, we considered cluster complexity by comparing performance on verbs with no cluster at the inflected verb end (e.g., *sewed*) versus those with a two-consonant cluster (e.g., *wrapped*) and three-consonant cluster (e.g., *danced*). The effects of phonological complexity might therefore partially explain why G-SLI children do not show the same advantage for regular over irregular verbs that typically developing children show. The majority of errors for all three groups were predicted to be bare stem forms (van der Lely & Ullman, 2001).

Results

Data from one participant in the TD1 group (who happened to be the youngest child) were discarded for two reasons. Firstly, her answers were at times muffled and therefore difficult to transcribe accurately. Secondly, assuming that her answers had been scored correctly, she achieved a score of 34.38%, which was 2.89 standard deviation below the mean for her group. Therefore these data represented an outlier performance of the TD1 group.

Analysis of correct responses

Correct responses to the elicitation task are shown in Table III. We carried out correlations for each group's correct performance against our lemma and past tense frequency measures. Not one correlation approached significance (Pearson values ranged between $-.260$ and $.239$, and p values between $.150$ and $.840$), and therefore we do not use frequency as a covariate in the analysis that follows.

We investigated the effect of phonological complexity by comparing verbs with no clusters, two-consonant clusters and three-consonant clusters at the inflected verb-end. Correct responses were analysed using a 3 (Group: G-SLI, TD1, TD2) $\times$ 3 (Condition: V-D, VC-D, VCC-D) ANOVA, and we applied Greenhouse-Geisser corrections because the data violated the assumption of sphericity. The analysis revealed significant main effects of complexity, $F(1.466, 76) = 5.498$, $p = .013$, and group, $F(2, 38) = 7.450$, $p = .002$, and a significant interaction

between condition and group, $F(2.931, 76) = 3.860$, $p = .015$.

The condition $\times$ group interaction was investigated with a series of pairwise comparisons between conditions within each participant group. For the G-SLI group, performance was significantly better for the V-D compared to the VC-D condition, $t(13) = 2.253$, $p = .042$, for the V-D compared to the VCC-D condition, $t(13) = 2.797$, $p = .015$, and for the VC-D compared to the VCC-D condition, $t(13) = 2.267$, $p = .041$. For the TD1 and TD2 groups, none of the pairwise comparisons reached significance, (t between $.322$ and 1.720 , and p between $.111$ and $.752$). The pattern of correct performance with respect to verb-end complexity was therefore $V-D > VC-D > VCC-D$ for the G-SLI group, but $V-D = VC-D = VCC-D$ for the controls.

The condition $\times$ group interaction was further investigated using a series of one-way ANOVAs within each condition, in order to identify group differences. For the V-D condition the effect of group was marginally significant, $F(2, 40) = 3.184$, $p = .053$. For the VC-D condition the effect of group was significant, $F(2, 40) = 7.745$, $p = .002$. Post-hoc testing, applying the Games-Howell correction for multiple comparisons where variances are unequal, revealed that within the VC-D condition, the G-SLI group performed worse than the TD1 controls, $p = .037$ and the TD2 controls, $p = .021$, but the two control groups performed equivalently, $p = .769$. For the VCC-D condition the effect of group was likewise significant, $F(2, 40) = 7.371$, $p = .002$. This time the G-SLI group did not perform significantly worse than the LA1 controls, $p = .064$, but did so compared to the LA2 controls, $p = .019$. Once again, the control groups did not perform differently from one another, $p = .258$.

Finally, we carried out correlations between correct score and complexity for each group, partialling out lemma and past tense frequencies. For the G-SLI group there was a significant negative correlation between score and complexity, $R = -.4782$, $p = .008$, whereas the correlations were not significant for the TD1 and TD2 groups, $R = -.1263$, $p = .506$, and $R = -.0876$, $p = .645$ respectively. These results confirm that the G-SLI children's inflectional accuracy was affected by increased complexity at the verb end, whereas that of the control groups was not.

Error analysis

Table IV shows the proportion of errors for each group and for each condition.

The most common error for all groups, as predicted, was the bare stem error. Deletion of a stem-final consonant was rare, and confined to VCC-D clusters. The examples were: *solved* $\rightarrow$ **sɒld/*, *milked* $\rightarrow$ **mɪlt/*, *banged* $\rightarrow$ **bænd/*. The G-SLI group made this error only 4 times (four

Table III. Correct responses for the elicitation task*.

Condition		G-SLI (N = 14)	TD1	TD2
			controls (N = 13)	controls (N = 14)
V-D	Mean (SD)	6.64 (1.65)	7.31 (.86)	7.71 (.61)
VC-D	Mean (SD)	5.75 (2.43)	7.62 (.71)	7.79 (.54)
VCC-D	Mean (SD)	5.07 (3.03)	7.15 (.90)	7.64 (.46)
All conditions	Mean (SD)	5.82 (2.37)	7.36 (.82)	7.71 (.54)

*For each cell, correct responses are out of a possible total of 8, with VC-D out of 16 but divided by 2 to be comparable to other cells.

Table IV. Error responses*.

Condition			G-SLI (N = 14)	TD1 controls (N = 13)	TD2 controls (N = 14)
Bare stem	V-D	Mean (SD)	.71 (1.27)	.54 (1.04)	.21 (.58)
	VC-D	Mean (SD)	1.75 (2.06)	.35 (.75)	.21 (.55)
	VCC-D	Mean (SD)	2.21 (2.42)	.62 (.77)	.36 (.63)
Stem-final C-deletion	V-D	Mean (SD)	n/a	n/a	n/a
	VC-D	Mean (SD)	.00	.00	.00
	VCC-D	Mean (SD)	.29 (.47)	.15 (.38)	.00
Other	V-D	Mean (SD)	.64 (1.15)	.15 (.55)	.07 (.27)
	VC-D	Mean (SD)	.50 (1.01)	.04 (.14)	.00
	VCC-D	Mean (SD)	.43 (1.09)	.08 (.28)	.07 (.27)

*For each cell, correct responses are out of a possible total of 8, with VC-D out of 16 but divided by 2 to be comparable to other cells.

different children), the TD1 controls only twice (two different children), and the TD2 controls not once.

In the “other” category, one child in the G-SLI group, OD, made 11 responses with *-ing* (omitting the auxiliary), e.g., **Yesterday I laughing* instead of *Yesterday I laughed*. This type of error was not made by any of the control children. The remaining errors made by the G-SLI and LA1 groups were phonological changes to the stem, e.g., **waved* for *weighed*, **saved* for *solved* and **sign* for *sighed*. The only error amongst the LA2 controls was an irregularization, whereby **/su:/** was produced in lieu of *sewed*.

It is difficult to argue that OD produces errors such as **Yesterday I laughing* in order to avoid the clusters that would result from inflection. We therefore carried out two further analyses to test our finding that phonological complexity does indeed impact on the accuracy of inflection. First, when we removed OD’s data from the analysis of correct scores, the effects of complexity, group and the interaction between complexity and group remained essentially unchanged. Secondly, an analysis of bare stem errors, using a 3 (Group: G-SLI, TD1, TD2) $\times$ 3 (Condition: V-D, VC-D, VCC-D) ANOVA, replicated our analysis on correct scores. Once again, we found significant effects of complexity and group, $F(1.492, 76) = 5.584$, $p = .011$ and $F(2, 38) = 5.770$, $p = .006$ respectively, and a significant interaction between complexity and group, $F(2.984, 76) = 4.223$, $p = .009$.

Discussion

In this study we set out to test the hypothesis that increasing the phonological complexity of the inflected verb end reduces the rate of successful past tense inflection for G-SLI children, but not for typically developing language-matched controls. The results support van der Lely and Ullman’s finding that G-SLI children perform worse than younger, language-matched control children on tasks eliciting regular past tense forms (van der Lely & Ullman, 2001). The majority of errors for all groups, as expected, were bare stem errors. The results go

further than that original study and also reveal that the phonological complexity of the verb-end affects the ability of children with G-SLI group to use the past tense suffix, over and above their deficits in morphosyntax. G-SLI children are less likely to inflect a verb when the inflected verb end would contain a cluster. Phonological complexity does not affect inflection in typically developing children (matched on other aspects of grammar and vocabulary) of the ages tested here, although it may well have done so at an earlier age (Bernhardt & Stemberger, 1998; Song & Demuth, 2005; Stemberger & Bernhardt, 1997).

The effect of phonological complexity on past tense inflection was predicted given findings that G-SLI children have difficulty repeating non-words containing consonant clusters (Gallon et al., under revision; Marshall et al., 2003). Compared to irregular verbs, regulars are more likely to have verb-end clusters, and so phonological complexity could be part of the explanation for the disproportionate difficulty that G-SLI children have with regular as opposed to irregular past tense morphology.

An alternative explanation for our results is that a processing or perceptual deficit caused the pattern of performance that we witnessed in the G-SLI group. Those accounts claim that deficits in processing the sorts of rapid temporal information that characterize the consonants /t/ and /d/ lead to a deficit in setting up the phonological representations for past tense, and hence to the suffix being omitted in production (Joanisse & Seidenberg, 1998, 2003; Leonard, 1998; McClelland & Patterson, 2002). However, there are several facts that militate such an account. Only a minority of children with G-SLI have an auditory deficit and there is no relationship between the magnitude of any auditory deficit and phonological, morphological and syntactic abilities. Indeed, many studies of SLI show that even the majority of SLI children in any one particular study do not have an auditory deficit (for a review, see Rosen, 2003). So although there is no doubt that auditory deficits and language impairments are co-morbid in some SLI children, there is no consistent causal relationship

between the one and the other. Nor can an articulatory deficit explain our results, because children are not included in the G-SLI subgroup if they have verbal dyspraxia. Once again, research in the SLI population as a whole shows no causal relationship between speech and language impairments; rather, there appears to be little overlap between children with speech impairments and those with language impairments (Shriberg, Tomblin, & McSweeney, 1999).

While phonology clearly plays a significant role in determining how successfully G-SLI children inflect verbs, locating the past tense deficit solely in the phonological aspects of language is too simplistic. A wealth of studies show that children with G-SLI have a range of syntactic and morphological deficits that cannot be accounted for solely by a phonological deficit (Marshall & van der Lely, 2006; van der Lely, 2003; van der Lely & Battell, 2003; van der Lely & Christian, 2000; van der Lely & Stollwerck, 1996, 1997). Instead, we propose that our data support the Computational Grammatical Complexity (CGC) Hypothesis, a model whereby independent deficits in syntax, morphology and phonology impact on regular past tense inflection. The production of regular past tense forms in English requires the production of complex syntactic, morphological and phonological structures, and children with G-SLI are impaired in producing exactly those types of structures. The CGC Hypothesis provides the most parsimonious explanation, not only for the past tense deficit, but for the full range of linguistic deficits seen in G-SLI.

Hypotheses which locate the deficit solely in the morphosyntax, e.g., the EOI/UCC Hypotheses (Rice & Wexler, 1996; Wexler, 1998), would not be able to account for the effects of phonological complexity that we have found, because the EOI/UCC Hypotheses do not predict any impact of phonology on past tense inflection. The EOI/UCC Hypotheses could provide an explanation for the morphosyntactic impairment in SLI children, and they might hold, of course, for certain groups of SLI children, but they cannot fully account for the performance of children who have a concomitant phonological deficit, such as those with G-SLI. It is likely that different explanations are required for different types of SLI. It is therefore important for the reader to note that we are making our claims for a set of children with well-defined characteristics—it remains an empirical issue as to whether our results will hold for other types of SLI. However, our work raises the possibility that the reason past tense inflection is such a good marker for English-speaking SLI children is that it involves complexity in syntax, morphology and phonology. Furthermore, the CGC Hypothesis predicts that the linguistic structures that are difficult for G-SLI children cross-linguistically will depend on the degree of syntactic, morphological and phonological complexity in the particular language under investigation.

We would like to propose that the CGC Hypothesis has at least one particular theoretical advantage over hypotheses that advocate a single deficit in SLI. Its approach to studying SLI involves disentangling how deficits in different components of language impact on a particular linguistic form, such as tense. Recent genetic findings inform us that SLI is not a unitary phenomenon. It is becoming clear that there is no single genetic 'cause' of SLI, and that genetic investigations require theoretically motivated measures of underlying cognitive abilities (Bishop, 2006). One locus on Chromosome 16 has been linked to performance on non-word repetition task, which is a phonological task, whereas a locus on Chromosome 19 has been linked to expressive language tasks that require syntax (SLI Consortium, 2002). Similarly, a behavioural genetics study by Bishop, Adams and Norbury (2006) implicated different genes appear in phonological short-term memory and verb inflection deficits in SLI. There is increasing recognition that when investigating the genetics of language, attention should be focused on the different components of language (e.g., Kovas et al., 2005) and on specifying the phenotype as precisely as possible (Fisher, 2005). Phenotypic investigations must go beyond the "tense is a marker for SLI in English" variety, by investigating which components of language are involved in linguistic phenomena such as tense marking and determining how these break down. Even though the relationship between genotypes and phenotypes is likely to be complex (Fisher, 2005), we need detailed phenotypic data to both drive the genotypic studies and interpret their results. Such investigations will serve to further our understanding of the nature of language, and ultimately our understanding of how specialized cognitive systems develop.

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Appendix 1. Details of the G-SLI participants (z-scores calculated on the basis of the published norms).

Code	Age	TROG (z-score)	BPVS (z-score)	NVIQ (z-score)	VATT (% correct)	TAPS (% correct)	A-STOP (% correct)
BD	9;09	-2.27	-2.10	-.07 ^{R+B}	12.50	39.58	54.17
SA	10;00	-1.73	-1.53	-.53 ^R	67.50	79.17	72.92
QC	10;02	-1.73	-1.93	-.93 ^R	10.00	64.58	43.75
HD	10;05	-2.40	-1.53	-.90 ^{BM}	n/a	60.42	n/a
CT	11;05	-2.07	-2.60	-.40 ^R	2.50	62.50	47.92
GS	11;08	-2.27	.80	-.85 ^{BM}	10.00	72.22	58.33
SL	11;10	-2.47	-1.90	.03 ^R	42.50	30.56	70.83
LJ	12;00	-1.20	-1.20	.53 ^{R+B}	72.50	54.17	80.56
OD	12;02	-2.07	-2.50	-.23 ^R	12.50	36.11	68.75
WS	13;00	-1.20	-.13	-.20 ^R	80.00	n/a	n/a
RP	13;06	-1.20	-1.33	-1.00 ^R	20.00	58.33	79.17
SM	13;09	-1.30	-1.60	1.15 ^{R+B}	12.50	n/a	n/a
GD	14;03	-.70	-2.20	-.71 ^{R+B}	27.50	62.50	n/a
CM	16;03	-.70	-2.00	-.07 ^{R+B}	60.00	n/a	n/a
Mean	12;03	-1.67	-1.53	-.30	36.96	55.67	62.15
(SD)	(1;11)	(.61)	(.76)	(.54)	(25.32)	(14.66)	(13.06)

TROG = Test for Reception of Grammar (Bishop, 1983); BPVS = British Picture Vocabulary Scales (Dunn et al., 1997); NVIQ = non-verbal IQ tests, ^R = Raven's Progressive Matrices (Raven, 1998); ^{BM} = Composite score of the Block Design and Matrices subtests from the British Ability Scales (Elliott, 1996) ^{R+B} = Composite score of Ravens and the Block Design subtest from the British Ability Scales; VATT = Verb Agreement and Tense Test (van der Lely, 2000); TAPS = Test of Active and Passive Sentences (van der Lely, 1996); A-STOP = Advanced Syntactic Test of Pronominal Reference (van der Lely, 1997).

Appendix 2. Verbs used.

Condition	Verbs	COBUILD		CHILDES	
		Lemma Frequency	Past tense frequency	Lemma Frequency	Past tense frequency
V-D	<i>poured*</i>	6.31	4.90	5.45	3.18
	<i>weighed</i>	5.58	3.69	3.81	1.95
	<i>paid</i>	7.69	6.13	5.37	3.71
	<i>sewed</i>	4.48	1.79	4.19	2.71
	<i>purred*</i>	3.56	1.79	1.79	.00
	<i>showed</i>	8.04	5.91	7.81	4.99
	<i>sighed</i>	5.18	4.51	1.79	.00
	<i>lied</i>	5.20	3.18	6.05	2.20
	Mean (SD)	5.76 (1.53)	3.99 (1.68)	4.53 (2.08)	2.34 (1.73)
VC-D	<i>hugged</i>	4.55	3.00	4.66	3.14
	<i>hummed</i>	4.88	2.48	4.74	3.56
	<i>robbed</i>	4.55	3.09	2.71	1.61
	<i>fished</i>	5.66	3.47	6.16	3.71
	<i>buzzed</i>	4.33	2.40	4.99	3.22
	<i>touched</i>	6.67	4.98	4.57	3.14
	<i>judged</i>	5.65	4.03	4.62	1.61
	<i>washed</i>	6.62	4.66	5.15	2.48
	<i>yelled</i>	5.67	3.74	4.66	3.14
	<i>wrapped</i>	5.59	4.48	4.74	3.56
	<i>tossed</i>	5.00	3.74	2.71	1.61
	<i>kissed</i>	6.08	4.74	6.16	3.71
	<i>killed</i>	7.21	5.81	4.99	3.22
	<i>packed</i>	5.26	4.26	4.57	3.14
	<i>coughed</i>	5.00	2.83	4.62	1.61
	<i>hopped</i>	4.29	2.64	5.15	2.48
	Mean (SD)	5.44 (0.90)	3.76 (1.00)	4.70 (.92)	2.81 (.80)
VCC-D	<i>pinched</i>	4.26	2.94	4.14	2.83
	<i>banged**</i>	5.11	3.14	5.55	3.04
	<i>winked</i>	4.20	2.83	2.40	.00
	<i>solved</i>	5.83	4.25	2.40	1.95
	<i>milked</i>	4.60	1.79	7.23	.69
	<i>punched</i>	4.30	3.04	4.81	2.08
	<i>munched</i>	3.99	1.79	1.39	.00
	<i>danced</i>	6.61	3.97	6.08	2.83
	Mean (SD)	4.86 (.93)	2.97 (.88)	4.25 (2.04)	1.68 (1.27)

*These two verbs do not end in a cluster for speakers whose accent is non-rhotic, as all our participants' are.

**The /g/ is pronounced in these participants' dialect.

Appendix 3*Stimuli***V-D**

Last year Kipper sewed a dress. Every year I sew a dress. Last year I . . . . .
 Yesterday Kipper sighed a bit. Everyday I sigh a bit. Yesterday I . . . . .
 Yesterday Kipper lied a bit. Everyday I lie a bit. Yesterday I . . . . .
 Last week Kipper paid a bill. Every week I pay a bill. Last week I . . . . .
 Last night Kipper poured a drink. Every night I pour a drink. Last night I . . . . .
 Yesterday Kipper weighed a parcel. Everyday I weigh a parcel. Yesterday I . . . . .
 Yesterday Kipper showed off to his friends. Everyday I show off to my friends. Yesterday I . . . . .
 Yesterday Kipper purred at a cat. Everyday I purr at a cat. Yesterday I . . . . .

VC-D

Last week Kipper killed a rat. Every week I kill a rat. Last week I . . . . .
 Yesterday Kipper hugged a friend. Everyday I hug a friend. Yesterday I . . . . .
 Yesterday Kipper kissed a girl. Everyday I kiss a girl. Yesterday I . . . . .
 Yesterday Kipper touched a flower. Everyday I touch a flower. Yesterday I . . . . .
 Yesterday Kipper packed a lunchbox. Everyday I pack a lunchbox. Yesterday I . . . . .
 Yesterday Kipper tossed a pancake. Everyday I toss a pancake. Yesterday I . . . . .
 Yesterday Kipper wrapped a present. Everyday I wrap a present. Yesterday I . . . . .
 Last week Kipper robbed a post office. Every week I rob a post office. Last week I . . . . .
 Yesterday Kipper buzzed at a bee. Everyday I buzz at a bee. Yesterday I . . . . .
 Yesterday Kipper fished in the river. Everyday I fish in the river. Yesterday I . . . . .
 Last year Kipper judged a competition. Every year I judge a competition. Last year I . . . . .
 Last winter Kipper coughed a lot. Every winter I cough a lot. Last winter I . . . . .
 Yesterday Kipper yelled at his mum. Every day I yell at my mum. Yesterday I . . . . .
 Last night Kipper hummed a tune. Every night I hum a tune. Last night I . . . . .
 Last night Kipper hopped around the bed. Every night I hop around the bed. Last night I . . . . .
 Yesterday Kipper washed a blanket. Everyday I wash a blanket. Yesterday I . . . . .

VCC-D

Yesterday Kipper winked at his mum. Everyday I wink at my mum. Yesterday I . . . . .
 Last month Kipper solved a crime. Every month I solve a crime. Last month I . . . . .
 Last week Kipper punched a burglar. Every week I punch a burglar. Last week I . . . . .
 Last night Kipper danced a jig. Every night I dance a jig. Last night I . . . . .
 Yesterday Kipper pinched a hamster. Everyday I pinch a hamster. Yesterday I . . . . .
 Yesterday Kipper munched a carrot. Every day I munch a carrot. Yesterday I . . . . .
 Yesterday Kipper milked a cow. Every day I milk a cow. Yesterday I . . . . .
 Last night Kipper banged on the door. Every night I bang on the door. Last night I . . . . .