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Grammatical language impairment and the specificity of cognitive domains: relations between auditory and language abilities

Heather K.J. van der Lely[a,*], Stuart Rosen[b], Alan Adlard[a]

[a]Centre for Developmental Language Disorders and Cognitive Neuroscience, Dept of Human Communication Science, University College London, 2 Wakefield Street, London, WC1N 1PF, UK
[b]Dept. of Phonetics and Linguistics, University College London, UK

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Abstract

Grammatical-specific language impairment (G-SLI) in children, arguably, provides evidence for the existence of a specialised grammatical sub-system in the brain, necessary for normal language development. Some researchers challenge this, claiming that domain-general, low-level auditory deficits, particular to rapid processing, cause phonological deficits and thereby SLI. We investigate this possibility by testing the auditory discrimination abilities of G-SLI children for speech and non-speech sounds, at varying presentation rates, and controlling for the effects of age and language on performance. For non-speech formant transitions, 69% of the G-SLI children showed normal auditory processing, whereas for the same acoustic information in speech, only 31% did so. For rapidly presented tones, 46% of the G-SLI children performed normally. Auditory performance with speech and non-speech sounds differentiated the G-SLI children from their age-matched controls, whereas speed of processing did not. The G-SLI children evinced no relationship between their auditory and phonological/grammatical abilities. We found no consistent evidence that a deficit in processing rapid acoustic information causes or maintains G-SLI. The findings, from at least those G-SLI children who do not exhibit any auditory deficits, provide further evidence supporting the existence of a primary domain-specific deficit underlying G-SLI.

Keywords: Grammatical-specific language impairment; Auditory abilities; Language acquisition

* Corresponding author. Tel: +44-20-7679-4047; fax: +44-20-7713-0861.
E-mail address: h.vanderlely@ucl.ac.uk (H.K.J. van der Lely).

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1. Introduction

An ongoing enquiry in cognitive science concerns the role of genes and environmental experience in shaping the development of specialised cognitive abilities. Most people acknowledge that both genes and environment are important in developing specialised systems. However, some researchers argue that domain-specific cognitive abilities develop from (genetically) pre-determined specialised mechanisms or neural circuitry (Chomsky, 1986; Pinker, 1994, 2002). Alternatively, others claim that specialised systems develop from more general-purpose mechanisms, becoming specialised through experience (Bates, 1993; Elman et al., 1996; Karmiloff-Smith, 1998). Importantly, according to Karmiloff-Smith and colleagues, there is unlikely to be pre-determination of mechanism (and, we presume, of neural circuitry) unique to a specialised ability and, therefore, pure primary impairments of specialised systems should not exist (Karmiloff-Smith, 1998; Thomas & Karmiloff-Smith, 2002). Moreover, Thomas and Karmiloff-Smith claim that there is no evidence for “residual normality” alongside any developmental deficit. Thus, this debate concerns basic questions about the development, structure and function of the brain.

The domain-specific perspective of cognitive abilities would be supported by the existence of developmental domain-specific deficits. Such evidence is, arguably, provided by “Grammatical-Specific Language Impairment” (G-SLI) (van der Lely, Rosen, & McClelland, 1998). SLI is a genetic deficit (Lai, Fisher, Hurst, Vargha-Khadem, & Monaco, 2001; SLI Consortium, 2002), heterogeneously affecting language acquisition in around 7% of children, who are otherwise apparently developing normally (Leonard, 1998). G-SLI children are a sub-group of the SLI population (van der Lely, 1996, 1998). Following extensive investigations of grammatical, non-grammatical language and non-verbal abilities, van der Lely and colleagues (e.g. Marshall, Harris, & van der Lely, 2003; van der Lely & Battell, 2003; van der Lely & Christian, 2000; van der Lely et al., 1998; van der Lely & Ullman, 2001) claim that G-SLI children have a relatively pure developmental domain-specific deficit in the grammatical aspects of language (syntax, morphology, and phonology) that are core to the human language faculty (Chomsky, 1995). Note that, although the grammatical deficit causes predictable secondary problems with word learning and therefore vocabulary knowledge (van der Lely, 1994; van der Lely, & Froud, 2002), this is, nonetheless, consistent with a domain-specific deficit (van der Lely, 2004). The grammatical impairments found in English speaking G-SLI children are supported by recent studies in other laboratories (Bishop, Bright, James, Bishop, & van der Lely, 2000), and cross-linguistic investigations in Greek and Hebrew-speaking G-SLI children (Friedmann & Novogrodsky, 2002, in press; Stavrakaki, 2001, 2002).

However, the grammatical specificity of the deficit in G-SLI has been challenged by researchers who suggest that G-SLI is caused by an auditory processing deficit which derives from a more general processing deficit, and is clearly outside the language system (Elman et al., 1996; Joanisse & Seidenberg, 1998; Karmiloff & Karmiloff-Smith, 2001; McClelland & Patterson, 2002; Tallal et al., 1996; Tomblin & Pandich, 1999). From this domain-general perspective, the link between auditory and grammatical deficits is as follows: In line with assumptions that experience determines the development of specialisation, a general deficit in processing speed, affecting auditory processing, causes

SLI, including G-SLI, by degrading the speech input. This auditory speech-processing deficit results in a failure to process non-salient morphemes such as regular past tense inflection, making them particularly vulnerable to impairment. Moreover, this impairment is presumed to underlie all other grammatical problems in G-SLI (Joanisse & Seidenberg, 1998; McClelland & Patterson, 2002). In support of this claim are reports that some children with SLI are: (1) impaired in discriminating speech sounds distinguished only by rapid acoustic transitions (/*ba*/-/*da*/, Tallal & Piercy, 1974); (2) impaired in discriminating rapidly presented non-speech tones (Tallal & Piercy, 1973; but see also Heath, Hogben, & Clark, 1999) and (3) that intensive auditory training, emphasising the perception of rapidly changing elements in speech and non-speech sounds, significantly improves speech discrimination and language comprehension (Merzenich et al., 1996; Tallal et al., 1996). This remedial effect is taken as strong support of the domain-general view of the underlying nature of SLI and the development of specialised linguistic abilities (Karmiloff & Karmiloff-Smith, 2001; Karmiloff-Smith, 1998).

Other evidence for this point of view is surprisingly patchy. First, there are very few reports of an auditory deficit in the perception of non-speech sounds in SLI listeners, with no convincing demonstrations of a non-speech deficit linked to a deficit in perceiving a speech contrast. Such demonstrations are crucial, as it is unclear how an auditory deficit in perceiving or processing speech sounds (phonological contrasts) (e.g. Hanson & Montgomery, 2002; Leonard, McGregor, & Allen, 1992) should be interpreted. A deficit involving phonemic (speech) contrasts could equally arise from a language deficit as opposed to a more general deficit in the auditory system. Thus, for our purposes, comparisons between speech sounds and their non-speech correlates are required. Secondly, many reports of auditory deficits are based on investigations of children with a *reading* disability (e.g. Mody, Studdert-Kennedy, & Brady, 1997), who do not necessarily have a more general language deficit. Third, some tasks used to investigate auditory processing have produced conflicting results. Whereas Wright et al. (1997), in a backward masking task, found no overlap between a group of 8-year old SLI children and their age-matched controls, Bishop, Carlyon, Deeks, & Bishop (1999), using the same task, found no difference between a group of LI children and controls. (For reviews of the relationship between auditory processing problems and language disorders such as dyslexia and SLI, see Ramus, 2003; Rosen, 2003). Therefore, in this investigation we explore auditory perception of speech and non-speech sounds; investigate a sub-group of SLI children who are known to have persisting and relatively restricted grammatical deficits; and use tasks that have most consistently been found to reveal auditory deficits in children.

If G-SLI children have an auditory processing disability, particularly if relations between their auditory and grammatical abilities are found, then this could count as evidence against the domain-specificity of their impairment. Therefore, we investigated auditory processing in our group of G-SLI children, probing just those auditory skills that have been claimed to underlie SLI. To evaluate the influence of age and language development on the task, we compared the G-SLI children's performance with age-matched and younger language-matched controls. Finally, we tested McClelland & Patterson's (2002) claim that a developmental phonological problem, caused by an auditory processing deficit, underlies SLI by exploring the relationship between auditory and phonological abilities.

We investigated auditory processing for three types of sounds using a same/different judgement of pairs of sounds, presented with a varying inter-stimulus interval (ISI). One pair was a synthesised /*ba*/-/*da*/, contrasting primarily in the second-formant transition. Difficulty in perceiving such brief formant transitions is claimed to be an essential feature of the auditory deficit underlying SLI (Tallal, 2000). However, any deficit revealed by using speech sounds could also arise from the phonological component of the grammatical system. Therefore, analogously to Mody et al.'s (1997) study of reading-disabled children, we also used isolated second-formants (*F2 alone*). These are not perceived as speech, yet still contain the same crucial acoustic feature. Finally, we used non-speech stimuli very similar to those used by Tallal and Piercy (1973) in their initial study of auditory processing in SLI—short complex tones differing greatly in fundamental frequency (*tones*)—as these stimuli, in particular, have consistently revealed deficits in language-disordered children (see Tallal, 2000).

Predictions:

1. If G-SLI children have a general auditory processing impairment then we would expect them to have difficulty in discriminating the pairs of sounds in each condition.
2. If, however, processing abilities specific to language affect auditory performance, then we would expect the G-SLI listeners to be (a) impaired on speech /*ba*/-/*da*/ but not the non-speech correlate (*F2 alone*) and (b) worse than age-matched, but not language-matched, controls.
3. If the auditory impairment is specific to rate of processing then we would expect G-SLI listeners to be able to discriminate the long ISI *tones* but not the short ISI *tones*. (ISI has little or no effect for the longer /*ba*/-/*da*/ and *F2 alone* stimuli).
4. If auditory processing impairment causes speech perceptual problems and inaccurate phonological representations, we would expect a direct relationship between auditory and phonological abilities.

2. Methods

2.1. Subjects

Four groups of subjects participated: a group of G-SLI children, and three groups of children who were matched on language abilities or age and IQ.

2.2. Selection of G-SLI subjects

There were 15 children (12 boys) with G-SLI (aged 12;5 to 19;3, mean 14;7) previously found to have a relatively pure deficit in grammatical abilities, and whose impairment, based on a preliminary study of first degree relatives, is consistent with an autosomal dominant inheritance (van der Lely, 1997; van der Lely et al., 1998; van der Lely & Stollwerck, 1996; van der Lely & Stollwerck, 1997). All of the G-SLI children had participated in a number of previous studies over some time (e.g. van der Lely, 1996;

van der Lely & Christian, 2000). This group, minus one boy, was the same as that which had participated in the van der Lely & Christian (2000) study.

Full discussion and details of the selection criteria are well documented (e.g. van der Lely, 1996, pp. 251–253), but for ease of reference we present a summary of the criteria below. The original selection was made from children who were more than 9;0 years of age[1] and were already diagnosed by speech and language therapists as having SLI: That is, they showed a significant impairment (< -1.5 SD) on one or more standardised language tests, and their non-verbal abilities were >85 as measured on standardised non-verbal IQ tests (British Ability Scales, Elliott, Murray, & Pearson, 1978; Raven's progressive matricies, Raven, Court, & Raven, 1978). Children with any deficits in neurological, motor or articulation abilities (e.g. dyspraxia) or psycho-social skills (e.g. Pragmatic impairment or attention deficits) were excluded. From this heterogeneous group of children with SLI, we selected the G-SLI sub-group. Selection criteria for the G-SLI sub-group included a persistent significant impairment on standardised tests tapping grammatical understanding of sentences and expression of language, e.g. TROG, a test of sentence understanding (Bishop, 1983); and the Grammatical Closure sub-test of the ITPA, a test of expressive morphology, (Kirk, McCarthy & Kirk, 1968). These standardised tests tap a range of morpho-syntactic as well as other language abilities (e.g. vocabulary), in some of which G-SLI children are impaired and some they are not. Therefore, in addition to the above criteria, to be included in the G-SLI sub-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 & Tense Test (VATT) van der Lely, 2000) and on a test of assigning thematic roles in reversible sentences (the Test of Active and Passive Sentences (TAPS) van der Lely, 1996). Tense marking has proved to be a good phenotypic marker of grammatical problems in SLI children (Rice & Wexler, 1996), and failure to reliably assign thematic roles in reversible sentences has been a consistent marker of the G-SLI sub-group (van der Lely, 1996; van der Lely & Dewart, 1986; van der Lely & Harris, 1990).

2.3. Overall characteristics of the G-SLI subjects

All the children in this study met the G-SLI criteria and on re-testing were now characterised by the following profile: a significant impairment (more than -1.5 SD) on one or more standardised tests tapping grammatical abilities involving sentence understanding and expression alongside vocabulary impairment. In addition, on specific tests tapping those aspects of morpho-syntax core to the deficit in G-SLI (e.g. tense & agreement, Wh-questions, assigning theta roles in passive sentences and intra-sentential pronominal reference) this group of G-SLI children were significantly worse than normally developing children of 5–6 years-old (van der Lely, 1996, 1998; van der Lely & Battell, 2003; van der Lely & Stollwerck, 1997; van der Lely & Ullman, 2001). Note that not all of these morpho-syntactic tests are used as selection criteria. Further, impairment in

[1] If SLI persists past 9 years of age, then from our experience, it is very unlikely that the problem will resolve, whereas this may not be so for children of 4–5 years of age.

phonological abilities is not a selection criterion for G-SLI. However, the majority (all but two) of the G-SLI children were also significantly impaired in their phonological abilities compared to children of 5–8 years with little overlap in scores (Gallon, 2002). The G-SLI subjects, but not language-matched controls, showed an incremental decrease in performance on a non-word repetition test as phonological complexity increased (Gallon, 2002). On non-grammatical language tasks, involving pragmatic inference or story-telling, and non-verbal tasks, they performed normally, in contrast to their grammatical abilities (van der Lely, 1997; van der Lely, 2004; van der Lely et al., 1998). Their mean IQ on the block design sub-test of the BAS was 108 (SD 15). In other aspects of their development, including hearing, they did not show any abnormality.

2.4. Age and language control groups

Fifteen children (14 boys), aged 13;9 to 17;9 (mean 15;6), served as IQ and chronological age (CA)—matched controls. All but two children were also matched on sex. Their scores on non-verbal IQ (103, block design, BAS) did not differ from those of the G-SLI group ($P = 0.22$). Two groups of younger children developing language normally were matched to the G-SLI subjects on different language tests in order that the effects of both grammar and vocabulary abilities (which do not develop synchronously in children with G-SLI) could be assessed. Twelve, younger language ability (LA1) controls (6 boys, mean age 7;4) were matched to the G-SLI subjects on two tests of grammar—the Test of Reception of Grammar (TROG) (Bishop, 1983), $P = 0.45$, and the Grammatical closure sub-test of the ITPA (Kirk et al., 1968), $P = 0.10$. A further 12 children (7 boys), the LA2 controls (mean age 8;7) were matched to the G-SLI subjects on receptive vocabulary (British Picture Vocabulary Scales (BPVS), Dunn, Dunn, Whetton, & Pintilie, 1982), $P = 0.750$.

2.5. Stimuli

Three pairs of sounds, differing primarily in a single acoustic feature, were generated using a software synthesiser (Klatt, 1980). Speech */ba/* and */da/* were based on the three formant stimuli specified by Mody et al. (1997). Steady-state formant frequencies were 750, 1200 and 2350 Hz. The first formant was identical for both stimuli, beginning at 200 Hz, and reaching 750 Hz after 25 ms. The second (F2) and third (F3) formants began at 825 and 2000 Hz for */ba/*, and 1500 and 2630 Hz for */da/*, reaching their steady-state values after 35 ms. Because F3 differed relatively little in onset frequency across the contrast (less than 0.4 of an octave), the phonetic distinction was carried almost completely by F2 (whose onset frequencies differed by more than 0.85 of an octave). For both syllables the fundamental frequency began at 121 Hz, rising to 125 Hz after 40 ms, and fell to 100 Hz at the end of the syllable. The total duration of each signal was 245 ms. Isolated second-formant (*F2 alone*) stimuli were obtained by outputting from the synthesiser the waveforms from the F2 resonator on their own. In order to make these sounds as un-speech-like as possible, they were synthesised on a monotone (121 Hz). Stimuli differing in fundamental frequency alone (*tones*) were generated on a neutral three-formant vowel (formant frequencies of 500, 1500 and 2500 Hz) by setting the fundamental frequency to be steady at either 100 or 305 Hz. A 50-ms section of each of these stimuli was excised, and ramped on and off with 5-ms raised-cosines. These are similar to, but shorter than, the stimuli described by Tallal and Piercy (1973).

Test trials consisted of two stimuli from the same condition presented sequentially with an ISI of 0, 10, 50, 100 or 400 ms. All 4 possible stimulus orders were presented (*e.g.* /*ba*/-/*da*/, /*da*/-/*ba*/, /*ba*/-/*ba*/, /*da*/-/*da*/). Test trials were presented in a random order with two occurrences of each ISI and stimulus order making 40 trials for each of the three conditions.

2.5.1. The same-different task procedure

After each trial, listeners responded by clicking with a mouse on a picture of two circles (*same*) or a triangle and a circle (*different*). A smiling or frowning cartoon face provided appropriate feedback. The task was demonstrated, followed by up to 40 training trials if required, before the test trials were begun.

2.5.2. Phonological ability

Scores were available from the Test of Phonological Structure (TOPhS) (Harris & van der Lely, 1999), a test which assesses phonological abilities by systematically varying the phonological structure of repeated non-words (van der Lely, 2004). Such tests are known to be sensitive to phonological problems (Bishop et al., 1999). Taking the basic phonological structure of a word (Harris, 1994), as shown in Fig. 1(a), this test varies the prosodic structural complexity of four basic novel word forms with respect to five parameters. Three parameters affect syllable structure (onset, rhyme, word-end) and two, metrical structure (left adjunction, right adjunction). A parameter can be either "marked" or "unmarked". The marked version is considered more complex, being acquired later and not attested in all languages (Harris, 1994). Examples of marked onset (Fig. 1b), rhyme (Fig. 1c), and left adjunction (Fig. 1d) are illustrated below. The combination of marked parameters was systematically varied to produce a set of non-words containing between none and 4 marked parameters. For each structural combination, there were four novel word stimuli, made up from the base forms, giving a total of 96 words to be repeated. The task took approximately 5–7 min to administer.

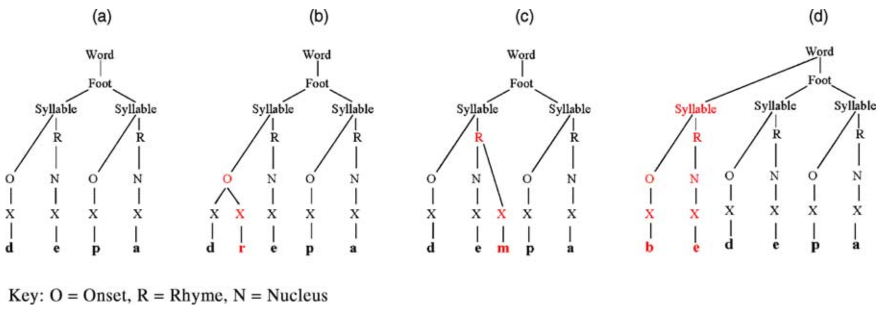

Fig. 1. Examples of prosodic structures used in the Test of Phonological Structure (TOPhS).

3. Results and discussion

Two sets of analyses were carried out; an individual subject analysis, and a group analysis. The former enables us to directly compare the children's auditory and phonological abilities in this study, as well as compare their auditory abilities with their grammatical abilities from previous studies. The group analysis allowed us to compare the results from this study with previous studies, where typically only group analyses have been conducted.

3.1. Individual analyses

We initially assessed whether each child in the G-SLI group was performing within the expected range for their age, as we had previously done with their grammatical abilities (van der Lely et al., 1998).

3.1.1. Speech (/ba/-/da/) vs non-speech (F2 alone)

Analogous to our previous analyses of grammatical abilities, taking only the data for the control listeners, first order (linear) regressions were carried out (as there was no statistical evidence of a quadratic trend) to predict the expected performance on the speech (*/ba/-/da/*) and non-speech (*F2 alone*) auditory tasks based on their age. Prior to the regressions, the data were screened for outlying values. A listener whose score fell more than 2 SDs below the mean (calculated within listener group and condition) had all of their data excluded. There were 7 such scores from five listeners (one from each of the control groups and two G-SLI subjects) that met this criterion. Then, for each G-SLI child, we computed the standardised residual (SR) score for the two auditory tasks. SRs are rescaled raw scores, with a mean of 0 and a SD of 1. Taking the conventional $+/-1.64$ SD as the normal range of abilities, 9 (69%) of the G-SLI subjects fall within normal limits on the *F2 alone* condition, whereas only 4 (31%) reach this level for */ba/-/da/*. This difference approached significance ($\chi^2(1) = 3.394$, $P = 0.065$). Note it was not the case that most of the G-SLI children were even generally below average abilities on the non-speech auditory task. Six G-SLI children (46%) scored >1 SD above that predicted for their age for the *F2 alone*. In contrast, only one (8%) did this well for */ba/-/da/*. Conversely, two (15%) of the CA controls fell below -1.64 on the *F2 alone* task, and 2 CA and one LA1 control fell below the expected range on the */ba/-/da/*. Thus, whereas for the speech contrast approximately one third of the G-SLI children's auditory abilities fell below that expected for their age, for the non-speech correlate the majority of the children fell within the normal range of abilities with almost half of the subjects falling in the top 16% of abilities.

3.1.2. Speed of processing (tones)

To assess whether speed of processing as measured by ISI differentially affected the G-SLI children's performance we calculated SRs (using the same method as above) for both the overall *Tones* condition and a sub-set of rapidly presented tones, i.e. tones presented at the 0 and 10 ms ISI (here after *rapid tones*). The same six children (46%) fell within the normal range both for the *tones* condition and *rapid tones* sub-set. Once again, it was not the case that most of the G-SLI children falling within the normal range exhibited generally below average abilities on the *rapid tones.* The same 5 (38.5%) G-SLI children scored > 1 SD above that predicted for their age on the *tones* and *rapid tones*. One subject from each of the control groups fell below − 1.64 on the *tones* and *rapid tones* condition. Thus, the results reveal no differential effect on performance when fast processing was required for either G-SLI children or normally developing children.

Finally, as some of the children in all of the groups performed poorly on the tests of auditory abilities, it is not the case that the experimental paradigm used to test auditory abilities is insensitive to deficits in children between the ages of 7–15 years—it clearly is. Indeed, one G-SLI child's SRs fell below − 1.64 on each of the tasks, indicating a genuine auditory deficit. Other G-SLI children who failed on one or more task evinced no predictable pattern across the tasks, except that they were more likely to fail the speech /*ba*/-/*da*/ than the other tasks. Further discussion of these findings will follow the group analysis.

3.2. Group analysis

The second set of analyses considered the patterns of performance within and across groups for the three auditory conditions and allows us to compare our findings with those from previous studies of mixed groups of SLI children. Most of the statistical analyses used logistic regression, analogous to analyses of variance and covariance, but appropriate for our task, where the response variable is binomially distributed (Collett, 2003). Fig. 2 shows that the G-SLI listeners' performance considerably overlaps with that of the controls in all three conditions. Analyses, however, revealed some differences in the pattern of performance across the conditions for the groups.

3.2.1. Speech (/ba/-/da/) vs non-speech (F2 alone)

A 4 (group) × 2 (condition: *ba*/*da*, *F2*) logistic regression with *ISI* as a continuous co-variate was carried out to see whether the difference in processing speech and non-speech

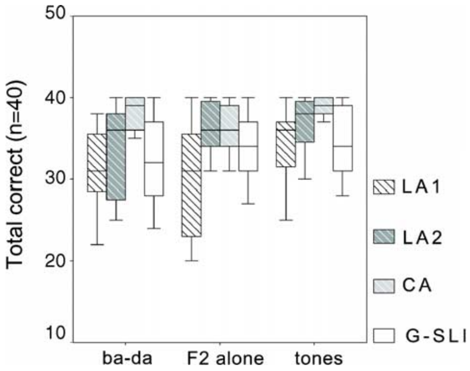

Fig. 2. Box-plots for the four groups' performance on the three auditory tasks, summed across ISI. The box indicates the inter-quartile range of values obtained, with the median indicated by the solid horizontal line. The whiskers show the range of measurements.

was the same for the G-SLI children as for the controls. A significant main effect of ISI was found ($\chi^2(1) = 14.7$, $P < 0.0001$), but there was no interaction involving ISI ($P > 0.6$). However, a significant group × condition interaction was revealed ($\chi^2(3) = 20.8$, $P < 0.001$). Therefore, the groups vary in their relative performance for the two conditions, but the effect of ISI is the same for all groups and conditions. Although the effect of ISI is highly significant, its magnitude is quite small, with performance ranging from a mean (over all groups and conditions) of about 82% for the shortest ISIs to 88% at the longest ISIs. Therefore all further analyses used numbers correct, summed over ISI.

We explored the group × condition interaction by comparing the G-SLI subjects with each control group. A 2 × 2 logistic regression (group: G-SLI, CA × condition: */ba/-/da/*, *F2 alone*) revealed a strong interaction ($\chi^2(1) = 8.494$, $P = 0.0036$). The G-SLI children's performance was significantly worse than that of the CA controls on both the */ba/-/da/* ($\chi^2(1) = 51.04$, $P < 0.0001$) and the *F2 alone* ($\chi^2(1) = 10.55$, $P = 0.0012$). Logistic regressions, comparing the two conditions within each group, revealed the source of the interaction. Whereas the CA controls showed a more consistent and higher performance for the speech stimuli than for *F2 alone* ($\chi^2(1) = 6.760$, $P = 0.0093$), the G-SLI group did not show any advantage for speech sounds ($\chi^2(1) = 1.970$, $P = 0.1604$) (see Fig. 2).

The analysis of the G-SLI and vocabulary-matched LA2 groups revealed significant main effects of group ($\chi^2(1) = 5.49$, $P = 0.019$), reflecting better performance by the LA2 controls, and condition ($\chi^2(1) = 10.43$, $P = 0.0012$), reflecting better performance with *F2 alone* than with */ba/-/da/*), but no interaction. Thus, the G-SLI subjects' pattern of performance was similar to, but lower than that of the vocabulary-matched LA2 controls.

Finally, comparison of the G-SLI and the grammar-matched, LA1 control groups' performance revealed a significant main effect of group ($\chi^2(1) = 12.15$, $P = 0.0005$), which, this time, reflected better performance by the G-SLI subjects. The interaction also approached significance ($\chi^2(1) = 3.56$, $P = 0.059$). Further comparisons revealed that the G-SLI subjects were significantly better than the LA1 controls on the *F2 alone* condition ($P < 0.0001$), but did not differ on */ba/-/da/* ($P = 0.26$). Once again, this reflects the G-SLI subjects' relatively better performance on non-speech than speech sounds.

In sum, the G-SLI children, as a group, are impaired in both conditions compared to age and vocabulary-matched controls but not grammar-matched controls. In contrast to the age-matched controls, the G-SLI children do not exhibit an auditory processing advantage for speech. If we considered only the group analysis, this would (incorrectly) suggest that there is a general auditory impairment in G-SLI children. However, this interpretation is not supported by the individual analysis, which reveals that only a sub-set of G-SLI children perform poorly on the non-speech correlate, whereas many perform appropriately for their age.

3.2.2. Speed of processing (Tones)

The final set of logistic regressions explored performance in the *tones* condition to assess whether speed of processing as measured by ISI differentially affected performance of the groups. Significant main effects were found for both ISI ($\chi^2(1) = 61.26$, $P < 0.0001$) and group ($\chi^2(3) = 57.96$, $P < 0.0001$). Further investigation showed that the G-SLI subjects' performance did not differ from the LA1 controls' ($\chi^2(1) = 2.25$,

$P = 0.1335$) and the difference from the LA2 controls did not reach significance level ($\chi^2(1) = 3.5$, $P = 0.067$). However, the G-SLI children's performance was worse than that displayed by the CA controls ($\chi^2(1) = 36.1$, $P < 0.0001$). For the typically developing children, a general developmental trend was evident with the LA1 controls performing worse than the LA2 controls ($\chi^2(1) = 10.4$, $P = 0.0012$), who in turn performed worse than the CA controls ($\chi^2(1) = 16.11$, $P = 0.0001$).

The group × ISI interaction was not significant ($\chi^2(3) = 4.41$, $P = 0.22$), although the LA1 and G-SLI groups showed a clear effect of ISI, whereas the CA group did not. However, this arises because the curve being fit to the data as a function of ISI is a sigmoid which asymptotes at perfect performance. This pattern is just like that reported by Tallal and Piercy (1973) which was claimed to be a selective deficit at short ISIs. The lack of interaction shows that it is not possible to know whether the deficit is restricted to short ISIs or not, as all groups show near perfect performance at long ISIs.

Thus, the results for the *tones* condition from this group analysis indicate that G-SLI children are impaired in their auditory processing in comparison to their age matched controls, and marginally so in comparison to their vocabulary but not their grammatical matched controls. However, once again, the individual analyses revealed that such an interpretation is only appropriate for a sub-set of the G-SLI children as almost half perform well within normal limits for their chronological age.

In sum, across the conditions, the pattern of results for speech sounds and their non-speech analogues differentiates the G-SLI and control groups' pattern of performance, whereas speed of processing as measured by ISI does not. The similarity in the pattern of performance and the lack of any interaction for short vs long ISIs between the G-SLI subjects and the control groups militates against a specific deficit for short ISIs, as proposed by Tallal and colleagues. Furthermore, the fact that the G-SLI subjects are relatively more impaired for the speech */ba/-/da/* as opposed to the non-speech *F2 alone* excludes an explanation of the deficit as arising from a specific difficulty with rapidly changing spectra. Thus, these findings do not support a general deficit in processing speed as the cause of SLI in general, and in particular, not in the G-SLI sub-group. However, although processing speed does not appear to characterise the findings, we note that one G-SLI child genuinely appears to have an auditory deficit, and some G-SLI children perform poorly on one or more auditory task. The question now arises as to whether there are any relations between the children's auditory performance and their language abilities.

3.2.3. Auditory performance and phonological abilities

To test whether auditory abilities were directly related to phonological performance, we compared the children's auditory abilities with their phonological abilities. Scores from the TOPhS were available from 11 G-SLI and 15 LA control children who participated in this study, therefore caution is expressed because of the small numbers involved. Fig. 3 shows performance on the ToPhS plotted as a function of the mean z-score of the 3 auditory tasks.

As can be seen from Fig. 3, one of the control children's TOPhS scores was almost 3 SDs below the rest of the group, so was excised from the analysis. The G-SLI children were classified into two groups on the basis of a z-score criterion which led to almost equal numbers of children in the two groups: poor listeners with a mean z-score < -1.64

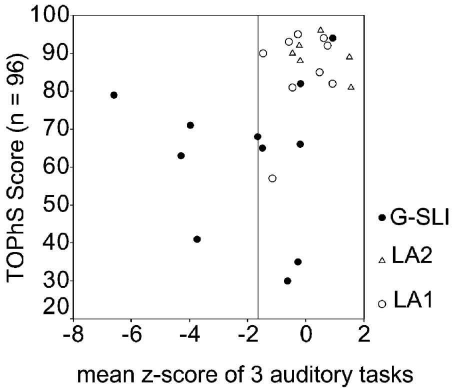

Fig. 3. Scatter-plot showing performance on the phonological task and the overall auditory performance for the G-SLI and language control subjects.

(5 children) and good listeners with a z-score greater than this (6 children). A t-test showed that performance on the ToPhS did not differ between these two groups ($P = 0.855$). No significant correlation was found between TOPhS abilities and overall auditory performance for the G-SLI subjects ($r(9) = 0.154$) (see Fig. 2) or the LA controls ($r(12) = -0.233$), or between the TOPhS and the individual auditory tasks ($P = 0.199$ to $P = 0.487$). Further, none of the auditory tasks correlated significantly with any of the grammatical assessments used in this study. Interestingly, for the control groups together, but not for the G-SLI children, vocabulary scores (BPVS) correlated significantly with both *F2 alone* and *tones* ($r > 0.34$, $P < 0.04$) but not */ba/-/da/* ($r = 0.12$, $P = 0.49$), with an even higher correlation being found when the non-speech tasks were summed ($r = 0.40$, $P < 0.02$). Insofar as vocabulary development is understood to depend on a whole host of non-linguistic cognitive as well as linguistic abilities, whereas grammar, arguably, does not, this is perhaps not too surprising. In sum, performance on these auditory, phonological, and grammatical tests is not directly related in normally developing children from 6 years of age or older children with G-SLI.

4. General discussion and conclusion

This study revealed that about half or more of the G-SLI children processed auditory non-speech sounds, with rapidly changing formant transitions and/or rapid presentation, normally for their age. The G-SLI children, were, generally, relatively worse at processing speech as compared to non-speech sounds than their age or language peers, with 31% as opposed to 69% falling within the normal range for their ages, for the speech and the non-speech correlates, respectively. Thus we failed to find a consistent, independent non-speech deficit linked to a deficit in perceiving speech contrasts.

The individual subject analysis revealed that the differences between the G-SLI and CA and LA2 control-groups result from a sub-group of the G-SLI children performing poorly on the auditory tasks. Therefore, the G-SLI group is not homogeneous with respect to auditory abilities. In contrast, many tests of grammatical abilities reveal a consistent deficit in G-SLI children, as is generally found in SLI children (Leonard, 1998; Rice & Wexler, 1996). Furthermore, individual analyses on grammatical tasks reveal that almost all, if not all, G-SLI children conform to the group pattern, and there is little overlap in performance between G-SLI children and language controls of 5-years-old upwards and no overlap with age-matched controls (Gallon, 2002; Marshall et al., 2003; van der Lely & Battell, 2003; van der Lely et al., 1998; van der Lely & Ullman, 2001). In addition, consistent with previous studies (e.g. Bishop, Carlyon et al., 1999; Neville, Coffey, Holcombe, & Tallal, 1993; Ramus, 2003), we found no direct relations between any of the auditory tasks (not even the speech task) and phonology—which is the most likely aspect of grammar to be affected—or any other grammatical measure. Thus, where auditory impairment does occur in G-SLI, it appears to have little consequences on grammatical abilities. The deficits in speech processing found in this and previous studies (Hanson & Montgomery, 2002; Leonard, McGregor, & Allen, 1992) could suggest that language-specific processing affects their auditory performance (rather than vice versa). However, we are cautious about this interpretation due to the lack of any relations between the auditory and grammatical tasks, including one tapping phonology. Additional investigations are warranted to investigate this further.

The finding of impaired auditory abilities in a sub-set of children is consistent with previous findings from reading-impaired children (Ramus, 2003) and a study of reading and/or language impaired children (Neville et al., 1993). Neville et al. (1993), using behavioural and imaging (ERP) techniques, found that a sub-set of reading and/or language impaired children performed poorly on auditory tasks, but, interestingly, these children were not the same as those performing poorly on grammatical tasks. Clearly there are some children with SLI, including some of those with G-SLI, who exhibit co-occurring auditory deficits. Caution is expressed, however, as only one G-SLI child exhibited a deficit on all auditory tasks and only around half of the children showed any deficits on any of the non-speech tasks. However, the incidence of auditory deficits in the G-SLI sub-group is more than might be expected, based on our typically developing population. A full theory of SLI will need to account for this fact. There is growing evidence from behavioural-genetic (twin) studies (e.g. Bishop et al., 1999) that auditory deficits result from environmental factors, whereas phonology and other grammatical abilities result from genetic ones (Bishop et al., 1999; Lai et al., 2001; SLI Consortium, 2002). Ramus (2002) suggests that environmental factors, such as excessive testosterone during brain development (Fitch, Brown, Tallal, & Rosen, 1997) may interact with genetic factors, thereby causing this greater-than-expected incidence of auditory impairments in children with language disorders (see Ramus, 2002, for further discussion).

It is evident from this study that not all of our G-SLI children exhibit “residual normality” (Thomas & Karmiloff-Smith, 2002). However, G-SLI when not accompanied by auditory deficits, appears to clearly provide the evidence for residual normality that Thomas and Karmiloff-Smith (2002) suggest is not plausible. However, the issue of residual normality is distinct from that of predetermined specialised systems. The disparate nature of the interaction of genes and the penetrance of alleles might mean that a particular genetic deficit could affect many independent, specialised cognitive systems—although the evidence from G-SLI suggests that this is not necessarily so.

Finally, the normal auditory processing in the majority of G-SLI children on the *F2 alone* condition militates against a (domain) general deficit in auditory processing causing G-SLI. Although it is possible that the G-SLI children with normal abilities had an auditory deficit at an earlier (critical) stage of development, we think this unlikely: First, because we found no relation between auditory and phonological or other grammatical abilities; second, because some G-SLI children were 1 sd. above the expected level of ability; and third, because some typically language developing children evince auditory deficits. Of course, this does not discount the possibility that an auditory processing deficit—although not one specific to speed of processing—could cause or exacerbate G-SLI or any other language disorder in some children.

The data from this study, alongside the growing evidence that different genetic disorders cause distinctly different forms of SLI (Lai et al., 2001; SLI Consortium, 2002), argue against a unitary hypothesis and explanation for the disorder. Regardless of the nature of altered molecular mechanisms and developmental neuronal pathways that underlie G-SLI, the evidence from this study, in at least those children without auditory deficits, substantiates our claim for the existence of a predetermined specialised sub-system in the brain required for grammar, which can be differentially impaired, and cannot be fully sub-served by more general mechanisms through development. Such "pure" cases of SLI, as found in G-SLI, although relatively rare, could play an important role in helping us understand the biology of typical and atypical language development.

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