Auditory Frequency Discrimination in Children With Specific Language Impairment: A Longitudinal Study

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It has been proposed that specific language impairment (SLI) is caused by an impairment of auditory processing, but it is unclear whether this problem affects temporal processing, frequency discrimination (FD), or both. Furthermore, there are few longitudinal studies in this area, making it hard to establish whether any deficit represents a developmental lag or a more permanent deficit. To address these issues, the authors retested a group of 10 children with SLI and 12 control children first tested 42 months previously. At Time 1, the children with SLI (between 9 and 12 years of age) had significantly elevated FD thresholds compared to the matched controls. At Time 2, the thresholds of both groups had improved, but the children with SLI still had poorer FD thresholds than those of the controls. To assess temporal resolution, auditory backward masking was measured and it was found that most of the children with SLI performed as well as the controls, but 2 children had exceptionally high thresholds. There was also greater variability among the children with SLI compared to that measured among the controls on the FD task. These studies indicate considerable heterogeneity in auditory function among children with SLI and suggest that, as with auditory temporal deficits, difficulties in FD discrimination are important in this population.

KEY WORDS: specific language impairment, auditory frequency discrimination, auditory temporal processing, language development

Specific language impairment (SLI) is a developmental disorder in which children are often late to start spontaneous speech and lag behind normally developing children in acquiring sophisticated language and grammar (Zangwill, 1978). Children with SLI have deficits in receptive and expressive language, and often have poor grammar, phonology, and semantic skills. Because of this broad span of both language and literacy deficits, some theorists have considered SLI to be a more extreme form of other language disorders, such as dyslexia, where oral language abilities are intact (Bishop & Snowling, 2004). It has been proposed that SLI may be due to cognitive and linguistic difficulties (Rice, Oetting, Marquis, Bode, & Pae, 1994; van der Lely & Stollwereck, 1997). However, other theorists have hypothesized that the primary deficit in SLI is in auditory processing (Tallal, 2000; Tallal & Piercy, 1973a, 1973b). This is not a hearing loss in the same way as deafness is, but rather an inability to perceive, categorize, and process sounds properly, which may lead to higher level problems. Such a "perceptual processing" view emphasizes the importance of the detection and discrimination of low-level, basic acoustic components, suggesting that these "bottom-up" problems interfere with higher linguistic processing.

Since the 1960s a number of studies have shown that some children with SLI have difficulty reporting the order of two sounds when these sounds are brief in duration and presented rapidly. Efron (1963) first suggested an association might exist between auditory temporal processing and language impairment. He noticed, when examining adults with aphasia due to temporal lobe disease, that their ability to listen to and repeat a simple tone sequence was impaired. He hypothesized that fundamental processes or mechanisms existed in the dominant temporal lobe, which were involved in "time labelling of input and output signals."

Efron's (1963) study was rapidly followed by suggestions that children with SLI may have similar temporal-processing deficits. For example, Lowe and Campbell (1965) compared the abilities of children with and without SLI using a temporal-order task. In this paradigm, children with SLI were asked to indicate verbally the sequential order of a high tone and a low tone that were separated by interstimulus intervals (ISIs) of different durations. The children with SLI required a mean ISI of 250 ms to discriminate between the two tones accurately, whereas control children were able to perform similarly with a mean ISI of 40 ms. Lowe and Campbell therefore concluded that children with SLI have a malfunction of temporal ordering that contributed significantly to their language difficulties.

Tallal and Piercy (1973a) modified Lowe and Campbell's task so that participants indicated the order in which a high tone and low tone were played by pressing appropriate panels on a button box. This task removed the need for a verbal response (which might be problematic for children with SLI) and became known as the auditory repetition task (ART). Control children performed significantly better than chance at the shortest ISI (8 ms), whereas the same level of performance was reached by the children with SLI only at an ISI of 305 ms or longer. The same pattern of results was seen using a "same–different" condition, for which children had to be able to discriminate the two tones but did not have to identify their order. This finding was taken as evidence that the children with SLI have a general impairment on tasks in which auditory stimuli are presented rapidly. This evidence led to the hypothesis that the primary auditory deficit in children with SLI was one of temporal processing (Tallal, 2000). This theory, however, has recently come under scrutiny from several researchers who have noted that the methods used to assess auditory skill (e.g., the ART) typically require the child to discriminate tones that differ in frequency and occur in rapid succession (McArthur & Bishop, 2001). This dual change in the auditory stimulus makes it difficult to tell whether impairments are due to difficulties in temporal or frequency discrimination (FD) or both. Could it be that the main auditory deficit in children with SLI is really one of FD? This hypothesis is supported by a growing number of findings. For example, in several studies using the ART in children who have language or literacy problems, a subgroup was omitted because they could not discriminate between tones of different frequency, even when there was no time pressure (Bishop, Carlyon, Deeks, & Bishop, 1999; Breier, Gray, Fletcher, Foorman, & Klaas, 2002; Heath, Hogben, & Clark 1999; Reed, 1989; Tallal & Stark, 1981). Also, investigators in several studies have found that children with language or literacy problems who did learn the initial tone discrimination have problems distinguishing tone sequences at both fast and slow rates (Bishop et al., 1999; Marshall, Snowling, & Bailey, 2001; Waber et al., 2001). Investigators using other paradigms have also shown that children with SLI have poor frequency discrimination. For example, McArthur and Bishop (2004b) found that a subset of participants with SLI had an FD deficit regardless of rate of presentation, and Wright et al. (1997) showed children with SLI were less able than the controls to take advantage of a frequency separation between a tone and masking noise in a backward-masking paradigm to aid the detection of the tone. Thus, one goal of the current study was to assess FD and temporal resolution in the same children, using separate tasks, to clarify the nature of any auditory deficit.

A second issue is whether perceptual deficits in SLI correspond to a developmental delay or a permanent deficit. Investigators in many studies have examined the nature and development of language skills over time. These investigators have shown that some children are late to start but then catch up with their peers (Whitehurst & Fischel, 1994; Paul, Hernandez, Taylor, & Johnson, 1996), whereas other children have persistent problems, with the pattern of their impairment changing over time (Bishop, 1994; Bishop & Edmondson, 1987). Despite this evidence of the changing nature of impairment, only a handful of studies have longitudinally followed the development of auditory processing in children with SLI. Instead, most investigators have focused on a snapshot of deficits at a particular time. Although many auditory abilities mature early in life, other skills do not reach adult levels until surprisingly late. For example, auditory backward-masking thresholds in typically developing children do not reach adult levels until the age of 12 (Hartley, Wright, Hogan, & Moore, 2000). Similarly, it has been proposed that FD ability is not adultlike until the ages of 7–9 years (Jensen & Neff, 1993). Therefore, one would expect that performance on the ART would change over time. The question then

becomes, "are children with SLI simply delayed in their development, or are their higher thresholds on the ART indicative of a more permanent processing problem?" This question has been investigated in only a small number of nonspeech studies.

Bernstein and Stark (1985) found that children with SLI had poorer performance than controls on the ART when they were tested at the age of 4–8 years. Many of the children with SLI found it difficult even to complete the association phase of the testing (learning to label the noises they heard as either "high" or "low" in pitch). When both groups were tested again 4 years later, the language abilities of both groups had improved, but the children with SLI had not caught up with the controls and had language levels more than 2 years behind their chronological age. Both groups performed at ceiling levels when retested on the ART. However, a deficit may have been present that went undetected because of the lack of task sensitivity.

A number of other studies have looked at longitudinal development of ART performance and its relation to language or literacy skills in typically developing samples. For example, Heath (2000) performed a longitudinal study of the ART in typically developing children who had good or poor phonological awareness (PA). She screened a sample of 106 preschoolers using a PA battery. The top and bottom quartile of these children were selected for further investigation. At their first testing, at the ages of 5–6 years, the children with good PA were significantly better on the ART than were the children with poor PA. The children with good PA also had significantly better receptive and expressive language abilities than did the children with poor PA. Three years later, at their second evaluation, the children with good PA were characterized by a pattern of general improvement on the ART (e.g., could distinguish between two tones at a shorter ISI than before). In contrast, only a third of the children with poor PA performed in the same range as did the controls. This pattern of results, however, was not seen by Share, Jorm, McLean, and Matthews (2002). They too screened a general population of kindergarten children for PA and ability on the ART. The children were retested at Grade 3, and reading ability also was assessed. The kindergarten performance of children who had gone on to become poor readers was then reanalyzed. When in kindergarten, these children who became poor readers were significantly worse than their peers on the ART for long ISIs, but there was no difference between the groups at short ISIs. The poor readers were retested in Grade 3 and their performances were compared to those for younger controls who had similar reading ability. No significant differences were observed in the performances of the two groups on the ART for either long or short ISIs. Thus, existing data do not agree on whether observed auditory deficits in SLI are transient delays or are more permanent deficits.

With the aims of addressing the nature (and course) of the SLI deficit, we retested a cohort of children with SLI and matched controls originally examined 30 months previously (Mengler, Hogben, Michie, & Bishop, 2005). The aims of the original study were threefold: (a) to determine whether a group of clearly defined children with SLI showed impaired FD; (b) if so, then to consider whether this is a general problem in doing any auditory psychophysical task or is specific to the frequency domain; and (c) to investigate any associations between FD, oral language ability, and reading skills. Fifteen children with SLI (mean age = 9 years 8 months) and 18 controls of matched age and ability were compared on an FD task. A control task measured intensity discrimination (ID), which is an auditory skill that matures early in childhood, before the age of 5 (Jensen & Neff, 1993). Performance, therefore, was expected to be adultlike in both groups on a measure of ID. The children with SLI had consistently higher thresholds on the FD task but were unimpaired on the ID task. They also had significantly poorer reading skills than did the controls. However, multiple regression analyses showed reading skill accounted for little variance in FD, whereas oral language explained a large, additional amount. Therefore, the study of Mengler et al. provided evidence for an FD deficit in children with SLI, related to their oral language ability rather than their reading skill. The Mengler et al. study, however, offers no insights as to whether the FD deficit is confined to early childhood or whether it persists into later development or adulthood.

In the current study we followed 10 of the children with SLI and 12 of the controls and retested them 3.5 years after the original study. Our first aim was to investigate the nature of the FD deficit previously observed in children with SLI. Secondly, we sought to determine whether the results of previous longitudinal studies using the ART were due to one particular auditory deficit or a combination of problems with both frequency and temporal attributes of processing (Bernstein & Stark, 1985). To evaluate this second issue, we used a backward-masking task. This task was chosen because backward masking has been shown to be impaired in younger children with SLI (Wright et al., 1997, but see Bishop et al., 1999) and because the normal developmental trends in performance on this task have been characterized well (Hartley, Wright, Hogan, & Moore, 2000). The backward-masking task is considered to be a measure of temporal resolution because it requires the participant to distinguish between sounds in time. FD ability was measured separately, and ID was included in the battery as a control task.

Method

All methods were approved by the Human Research Ethics Committee of the University of Western Australia. Informed consent was obtained from each listener and assent was provided by his or her parent or guardian to participate in the research.

Participants

All of the children who had participated in the previous study (i.e., Time 1) were contacted 42 months later. Ten of the 15 original children with SLI and 12 of the 18 original control sample agreed to be retested. In the current study, 2 of the controls and 1 child with SLI were females. The mean age of the control group at the time of the second test (i.e., Time 2) was 13 years 5 months (ages ranged from 12 years 7 months to 14 years 7 months). The mean age of the children with SLI was 13 years 2 months (ages ranged from 11 years 11 months to 15 years 2 months). The hearing sensitivity in these children was normal at the time of the previous audiological measurements (Mengler et al., 2005).

Stimuli and Procedures

All stimuli were generated in software and presented by Tucker-Davis Technologies (TDT) System II hardware under PC control and were identical to those described in Mengler et al. (2005). Stimuli were presented binaurally via headphones (Sennheiser Model HD265).

Frequency Discrimination

FD thresholds were estimated using a three-interval, two-alternative forced-choice, AXB procedure. Three tones were presented in each trial. All tones were 100 ms in duration, separated with ISIs of 300 ms, and each was presented at 83 dB SPL. The first tone (A) was a 1000 Hz standard, the third tone (B) was the same frequency (i.e., 1000 Hz) plus some frequency difference, and the middle tone (X) matched the frequency of either the first tone or the third tone on a random basis. The initial stimulus difference was 30 Hz and was modified using a parameter estimation by sequential testing procedure (Taylor & Creelman, 1967). This procedure presents large frequency differences that initially are easily discriminable. The frequency differences are systematically reduced in a stepwise protocol, and the task becomes more and more difficult until an error is made. After an error is made, the frequency difference is increased to make discrimination easier (a reversal). Step size is then progressively reduced again, until a threshold level is reached

for which the child responds at a level of 75% correct. The maximum step size used in the measurements was 8 Hz, and the minimum step size was 0.1 Hz. The threshold value for a block of trials was the mean difference in hertz between the middle (variable) tone and the 1000 Hz standard tone after the fourth reversal in the PEST staircase had been reached. Each child completed three blocks of trials, with each block comprising 60 trials.

Testing was conducted in an acoustically treated room. The child was seated in front of a computer screen and required to identify whether the middle sound was the same as the first sound or the last sound. They indicated their choice by pressing the appropriate button on a keypad. Feedback was provided in the form of a happy or a sad face that briefly appeared on the screen.

Training was given to all children to familiarize them with the task. This involved setting the stimulus parameters to a frequency difference of 200 Hz, with an ISI of 500 ms. There were three stages of training. Initially, the procedure was demonstrated to the child with picture reinforcement; next, the child performed 15 trials, again with visual cues; and, finally, the child performed another 15 trials, but without the visual cues. The test commenced only if the child achieved a minimum performance of 75% correct at this stage.

Intensity Discrimination

An ID measurement served as a control task. This task used the same PEST procedure as did the FD task. The tones again were 1000 Hz in frequency and 100 ms in duration, but they were manipulated to differ in intensity. The intensity of the standard tone was 83 dB SPL. A 6 dB difference was used for training and practice sessions and also as the initial difference at the start of the PEST staircase procedure. The starting step size was 1.5 dB with a maximum of 3 dB and a minimum of 0.1 dB.

Backward Masking

The signal to be detected was a 20 ms pure tone with a frequency of 1000 Hz. The signal was gated on and off with 10 ms raised-cosine ramps and with no steady state portion. The masker was a 300 ms burst of band-pass noise centered at 1000 Hz with a bandwidth of 800 Hz. It was also gated with 10-ms raised-cosine ramps and had a 280 ms steady-state portion. The noise spectrum level within the masker passband was 53 dB (re: 20 μPa). Two masker bursts, separated by 800 ms, with the signal were presented randomly before either the first or the second masker burst. There was no silent interval between the offset of the signal and the onset of the masker. The level of the signal was

Table 1. Means and standard deviations for the control and SLI groups on the frequency-discrimination (FD), intensity-discrimination (ID), and backward masking (BM) tasks at Time 1 and Time 2.

Condition	Controls		SLI		Comparisons
	M	SD	M	SD	
Mean FD T1 (Hz)	24.6	15.3	51.8	25.5	$t(20) = 3.1$, $p = .006$
Mean FD T2 (Hz)	18.7	11.2	37.5	19.0	$t(20) = 2.9$, $p = .009$
ID T1 (dB)	2.6	0.9	3.3	1.6	$t(20) = 1.2$, $p = .23$
ID T2 (dB)*	2.1	0.9	2.9	1.2	$t(16) = 1.2$, $p = .15$
BM T2 (dB SPL)	36.9	1.9	47.1	21.1	$z = 1.6$, $p = .11$

Note. Because of technical problems at Time 2, ID thresholds from 2 participants in each group are missing.

variable and was controlled by the computer. A PEST procedure was again used to determine the signal level on a given trial within the block of 60 trials. The initial signal level was 70 dB SPL, with a maximum step size of 5 dB and a minimum step size of 1 dB. Two threshold estimates were measured and averaged.

Language Tests

All children were assessed with a short battery of ability tests, lasting approximately 30 min. Nonverbal intelligence was measured using the Wechsler Abbreviated Scale of Intelligence (WASI) Matrices subtest (Wechsler, 1999). For each item, the child was shown a grid of patterned tiles in which one tile was missing. Six alternative, differently patterned tiles were displayed and the child had to select which of these best completed the grid. Oral language competence was assessed using two subtests from the Clinical Evaluation of Language Fundamentals—Third Edition (CELF–3; Semel, Wiig, & Secord, 1995), a test battery that is widely used in the diagnosis of SLI. The first subtest was Concepts and Directions, which is a measure of receptive language. In this task, the child listens to a list of verbal commands to point to a sequence of shapes in some correct order. In the second subtest, Recalling Sentences, the participant listens to and repeats a sentence of increasing complexity. This task, which taps expressive language ability, has been shown to be a particularly sensitive measure of SLI (Conti-Ramsden, Botting, & Faragher, 2001). Criteria for inclusion in the SLI category were based on performance of the same language tests at Time 1 (Mengler et al., 2005). All the children in the SLI group scored more than 1 *SD* below the level expected for their age on the receptive and/or expressive CELF–3 subtests described above. The control children performed within the average range on both tests, and there was no overlap in ability between the two groups. Reading also was assessed at Time 1 using subtests of the Woodcock Reading Mastery Test (Woodcock, 1987) and at Time 2

with the Test of Word Reading Efficiency (TOWRE; Torgesen, Wagner, & Rashotte, 1999). For the latter task children were asked to read as many items as they could in 45 s. There are two subtests for the TOWRE; one uses real words and the other uses nonsense words.

Results
Frequency Discrimination

The range of thresholds for the control children was 6–37 Hz, with a mean threshold of 18.7 Hz, and for the children with SLI the range was 15–76 Hz, with a mean threshold of 37.5 Hz (see Figure 1 and Table 1). An analysis of variance (ANOVA) was performed to compare the performance of the two groups. However, the Levene test showed that there was a difference in the homogeneity of variance between the groups for the third block, $F(1, 20) = 10.4$, $p = .04$. A Kruskal–Wallis test was performed to compare the three FD blocks between the two groups. This analysis revealed significant differences between the groups for each block (Block 1: $p = .03$, Block 2: $p = .02$, Block 3: $p = .01$), indicating that the children with SLI had significantly higher FD thresholds than the controls for each block.

To increase statistical power and to control for the effects of outliers, the mean value of all three blocks was used as the measure of FD. To investigate the validity of this approach, a *t* test was performed on the mean thresholds of both groups. There were no differences in the homogeneity of variance between the groups on the Levene test, $F(1, 20) = 0.6$, $p = .47$, but the children with SLI had significantly higher FD thresholds than did the controls, $t(20) = 3.0$, $p = .007$. The difference on average between the thresholds for the children with SLI (37.5 Hz) and those for the controls (18.7 Hz) was twofold.

Figure 1. The three frequency-discrimination threshold estimates for both groups are shown by box plots at Time 2. FD 1 = Threshold Estimate 1, FD 2 = Threshold Estimate 2, FD 3 = Threshold Estimate 3. The interquartile range of values obtained is represented by the box, with the median represented by the solid horizontal line. The range of measurements is shown by the whiskers, except for points more than 1.5 (indicated by "o") or 3 box lengths (indicated by "*") from the upper edge of the box.

Figure 2. Box plots showing the mean frequency-discrimination thresholds for both groups from Time 1 (data collected by Mengler et al., 2005) and Time 2 (the findings of the present study). The interquartile range of values obtained is represented by the box, with the median represented by the solid horizontal line. The range of measurements is shown by the whiskers.
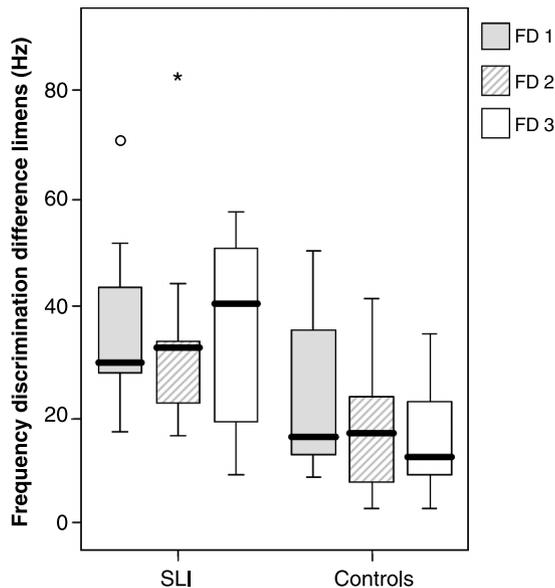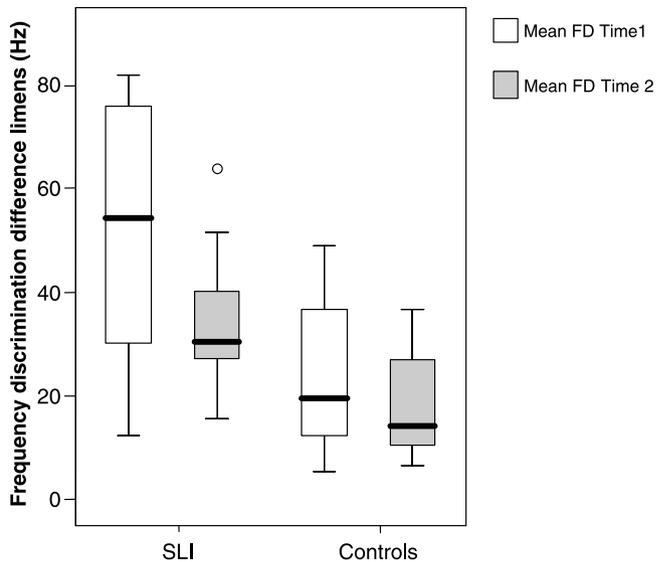

Comparison of Mean FD Performance at Time 1 and Time 2

To recap, the mean (*SD*) thresholds of the children with SLI in the first study (Time 1) were 51.8 (26) Hz, and in this study (Time 2) they were 37.5 (19) Hz. The mean thresholds of the control children at Time 1 were 24.6 (15) and at Time 2 were 18.7 (11.2) Hz. The difference in performance of the children at Time 1 and Time 2 was analyzed using a repeated-measures ANOVA with two levels: Time × Group (SLI and control). A Levene's test of the homogeneity of variance was not significant, indicating that parametric statistics were appropriate to use. There was a significant effect of group, $F(1, 20) = 11.1$, $p = .003$, and of time, $F(1, 20) = 11.9$, $p = .003$, but no interaction between group and time, $F(1, 20) = 2.7$, $p = .11$.

Given the debate concerning developmental delay in auditory processing in children with SLI, it is notable in Figure 2 that there was no significant difference between the control average thresholds at Time 1 (24.6 Hz) and the SLI performance at Time 2 (37.5 Hz), $F(1, 20) = 1.7$, $p = .09$. When the Time 1 ID thresholds were included in the analysis as a covariate, the results did not change, suggesting that the findings were not due to differences in task performance ability of the groups.

Intensity Discrimination

Because of technical difficulties, it was not possible to obtain ID thresholds for 2 of the children with SLI and 2 of the controls. The range of ID thresholds for the control children was 1.1–3.6 dB, with a mean threshold of 2.1 dB. For the children with SLI, the range of ID thresholds was 1.9–5.3 dB, with a mean value of 2.9 dB. There was no difference in the homogeneity of variance of the mean ID thresholds for the two groups on the Levene test ($F = 3.5$, $p = .08$), nor was there a significant difference between the groups on this task (see Table 1 and Figure 3). Because the ID task is otherwise similar to the FD task, except for the manipulation of the intensity differences between the stimuli, this result suggests that the two groups of children did not differ in their abilities to perform the basic psychophysical task. Rather, they differed in their abilities to discriminate the frequencies of the tones.

Backward Masking

The backward masking thresholds measured for the two groups were evaluated by Levene's test for the homogeneity of variance. This analysis yielded a significant outcome ($F = 16.1$, $p = .01$), so a Mann–Whitney *U* test was performed to compare mean group values. There was not a significant difference between the SLI group mean threshold (47.1 dB SPL) and the control

Figure 3. Intensity-discrimination thresholds for both groups, at Time 1 (ID 1) from Mengler et al. (2005) and at Time 2 in this study (ID 2). The interquartile range of values obtained is represented by the box, with the median represented by the solid horizontal line. The range of measurements is shown by the whiskers.

Figure 4. Box plots showing the backward-masking threshold estimates of both groups. The interquartile range of values obtained is represented by the box, with the median represented by the solid horizontal line. The range of measurements is shown by the whiskers, except 3 box lengths (indicated by ''*'') from the upper edge of the box.
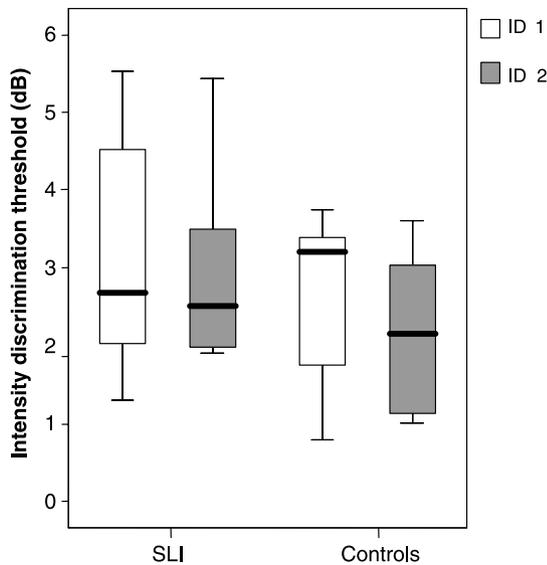
group mean threshold (36.9 dB SPL) for the backward masking task ($p = .31$) (see Figure 4). For the majority of children in both groups, the backward masking thresholds fell within an adult range (Hartley et al., 2000).

Two of the children with SLI had backward masking thresholds that were more than 1 *SD* higher than the thresholds of all the other participants (shown as outliers in Figure 4 by asterisks). These 2 children were not poor performers on other auditory or language tasks. Their auditory thresholds and language scores are shown in Table 2.
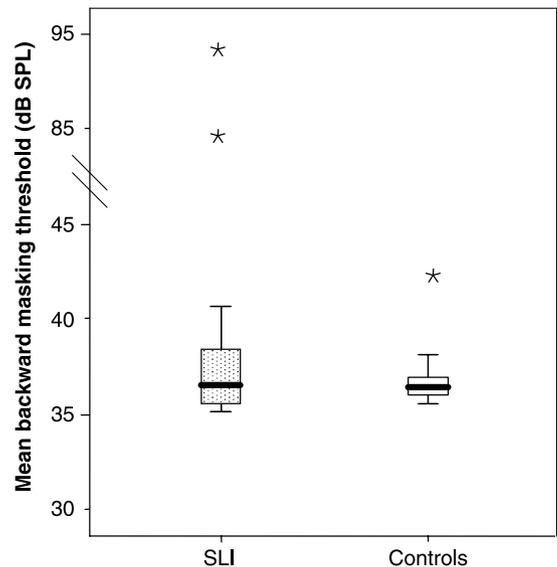
Language and Reading Measures

Although both groups were well matched for nonverbal intelligence, the SLI group was significantly poorer than the control group on all measures of language and reading (see Table 3). Even with the 42 month time lapse between Time 1 and Time 2, the children with SLI did not catch up with the control group.

Discussion
Evidence for Frequency and Temporal Deficits in SLI

The FD abilities of both groups improved over the 42 months between testing sessions at Time 1 and Time 2, but the children with SLI remained signifi-

cantly poorer on the FD task than did the controls. As discussed in the introduction, a small number of previous studies have investigated the development of FD in children with language or literacy problems. It is difficult to make direct comparisons between the present study and these previous investigations for two reasons: (a) the children in our study were older than those in the other studies, and (b) previous studies mainly used the ART, rather than separate FD and temporal-processing tasks. Nevertheless, our study reflects broadly similar findings to those reported by Heath (2000), who showed decreased improvement over time in children with poor PA compared to children who had good PA. However, our findings disagree with those of Share et al. (2002), who found no difference in the auditory abilities of children with good and poor PA when tested for the second time.

The present study also investigated the abilities of children on a backward masking task. The majority of children had adultlike backward masking thresholds, as would be expected for children of their age (Hartley, Wright, Hogan, & Moore, 2000). This finding suggests that if tested with the ART, this sample of children with SLI would be likely to have problems with FD rather than with temporal processing.

Because backward masking was not tested at Time 1, we cannot comment here on its developmental

Table 2. Auditory thresholds and language measures of two children with significantly elevated backward-masking thresholds are compared with the remainder of children with SLI.

Child identification no.	BM threshold (dB SPL)	FD threshold (Hz)	Mean ID threshold (dB)	Matrices test[a]	Expressive Language[b]	Receptive Language[b]
4	85.8	31.85	1.9	54	6	2
8	88.2	40.33	4.7	54	3	7
Mean of remaining sample	37.2	38.8	2.9	45	4	6

[a]Matrices score expressed as T scores ($M = 50$, $SD = 10$). [b]CELF–3 scores expressed as T scores ($M = 10$, $SD = 3$).

time course. Nevertheless, it is clear that at Time 2 the majority of children with SLI performed as well as did the controls. Two children with SLI had backward masking thresholds that were 1 SD or more greater than the values measured for the rest of the group. Possible reasons for these outliers are discussed below.

Do FD deficits behave like maturational lag or permanent deficit? It is well known that auditory systems have a protracted course of development in typically developing children. This has been shown using electrophysiological techniques in children with profound deafness who have received cochlear implants (Ponton & Eggermont, 2001) and in studies of normally developing children and adolescents (Ponton, Eggermont, Kwong, & Don, 2000). There is also some immunohistochemical evidence for delayed maturation in the study of Moore and Guan (2001), who found that

the neurofilament expression of axons in the auditory cortex does not appear to be mature until age 11–12. This finding raises the question of whether a delay in the maturation of auditory processing can cause the auditory problems observed in children with SLI.

The majority of the children in this study improved their FD abilities over the 42 months between testing. However, there is little previous empirical evidence for delayed FD ability in children with language problems. Normally, FD abilities for brief duration tones mature after the age of 6 or 7 years (Jensen & Neff, 1993; Thompson, Cranford, & Hoyer, 1999), and there was a tendency, albeit not significant, for improvement in the control group between Time 1 and Time 2. There was no significant difference between the groups on the ID task at either Time 1 or Time 2, indicating that even if the children with SLI were developmentally delayed in

Table 3. Language, reading, and nonverbal intelligence measures of both groups.

	Controls		SLI		
	M	SD	M	SD	Comparisons (t tests)
Time 1					
Expressive Language[a]	10.2	3.2	3.9	1.4	$t(20) = 5.7$, $p < .01$
Receptive Language[a]	12.8	2.5	6.7	2.4	$t(20) = 5.8$, $p < .01$
Sight Word Reading (WI)	108.5	13.0	85	12.2	$t(20) = 3.1$, $p < .01$
Nonword Reading (WA)	107.3	10.6	93	11.3	$t(20) = 4.3$, $p < .01$
Time 2					
Matrices[b]	47.4	6.7	48.3	7.8	$t(20) = 0.3$, $p < .78$
Expressive Language[a]	8.6	2.3	4.2	1.6	$t(20) = 5.1$, $p < .01$
Receptive Language[a]	9.3	2.5	5.8	2.7	$t(20) = 3.2$, $p < .01$
Sight word efficiency (Sight Word Reading)[c]	108.7	15.7	87.2	14.8	$t(20) = 3.3$, $p < .01$
Nonword Reading (phonetic decoding)[c]	107.3	23.4	86.7	19.8	$t(20) = 2.2$, $p < .01$

Note. WI = Word Identification, the Woodcock Reading Mastery Test Sight Word reading subtest, WA = Word Attack, the Woodcock Reading Mastery Test Nonword Reading subtest. Both have a mean of 100 and standard deviation of 15.

[a]CELF–3 scores expressed at T scores ($M = 10$, $SD = 3$). [b]Matrices expressed as T scores ($M = 50$, $SD = 10$). [c]Test of Word Reading Efficiency scores are percentiles ($M = 50$, $SD = 15$).

their ID in early childhood, they had reached mature levels by the time they were tested by Mengler et al. (2005). Nevertheless, despite their mature performance on the ID task at the present time, the children with SLI have significantly higher thresholds than those of the controls on the FD task. There is a trend suggesting the children with SLI may be developmentally delayed relative to controls on the FD task, but further data are needed to confirm this. For example, if thresholds were collected from these children at future time points it would be possible to see if the SLI group did indeed reach adult levels, and at what stage this occurred relative to the control group.

There is growing evidence that children with language or literacy problems may also have delayed development of other auditory skills. For example, Wright and Reid (2002) showed that 12-year-old children with SLI had thresholds for simultaneous, backward, and forward masking that were significantly different from age-matched controls but not significantly different from 8-year-old controls. This finding suggests a delayed development in the children with SLI for a range of masking tasks. However, developmental delay in the group of children with SLI in the present study cannot be confirmed unless the children are retested at a future date and shown to have reached adult levels. A similar finding also has been reported by Hautus, Setchell, Waldie, and Kirk (2003). They showed that 6–9-year-old children with dyslexia were impaired at a gap detection task relative to age-matched controls. This pattern of results was not seen in groups of older children and in adults with dyslexia. Hautus and colleagues concluded that early temporal-resolution deficits observed in the children with dyslexia significantly improved over time. However, they also suggested that auditory-processing deficits measured in children who are young may be antecedent to other language-related perceptual problems (particularly those related to phonological processing) that persist after the primary deficit has resolved. These previous reports and the findings from the present study indicate that children with learning and language difficulties who also have poor auditory-processing abilities are able to improve their auditory skills over the course of their development. Additional research is necessary to determine (a) whether these children ever catch up fully with their peers over time and (b) whether impaired auditory processing when young is associated with lasting language-related difficulties.

Individual Differences

A number of studies have shown that the auditory deficits observed in SLI are heterogeneous, with much interparticipant variability (McArthur & Bishop, 2001, 2004a, 2004b). A similar pattern of results was observed in the present study on the backward masking task, where 2 children with SLI had thresholds that were significantly higher than those of the rest of the group. Such findings have led to hypotheses that children with SLI may comprise a number of subgroups with different underlying causes, but all presenting with similar symptoms, namely, poor expressive and receptive language (Heath, Hogben, & Clark, 1999; McArthur & Hogben, 2001). For example, investigators in several studies have reported that a subset of people with SLI who have concomitant reading deficits are likely to perform more poorly on auditory tasks than are those who are impaired in only one of these areas (Heath, Hogben, & Clark, 1999; McArthur & Hogben, 2001). In this study, the poor performance of 2 children on the backward masking task may indicate that in addition to having an FD impairment, they have additional difficulties with temporal resolution that are not observed in the other children (see Table 2). One of these 2 participants also had significantly elevated ID thresholds compared to the control data. This child had ID problems, in addition to other auditory processing difficulties, that may contribute to his higher backward masking threshold.

The influence of top-down processes in psychophysical tasks also needs to be investigated. Although the children with SLI had poor FD abilities, this apparent deficit is unlikely to be due to overt inattention because there was not a significant difference between the two groups on the control ID task. Several studies have reported FD deficits in participants with language and literacy problems such as SLI and dyslexia using evoked response potentials that required no response from the participant (Baldeweg, Richardson, Watkins, Foale, & Gruzelier, 1999; Bishop & McArthur, 2005). This adds support to the argument that poor FD measured psychophysically is not a mere reflection of poor attention (Baldeweg et al., 1999). Taken together, these findings suggest that impaired FD as measured psychophysically is not an artifact of inattention, and that poor FD may contribute significantly to SLI.

Conclusions

The findings from our FD and backward masking measurements suggest that children with SLI in their early teenage years may have FD deficits and may also have additional temporal-processing problems. This finding is congruent with a small number of studies investigating the role of FD in people with language or literacy problems (Amitay, Ahissar, & Nelkin, 2002; Bishop & McArthur, 2005; McArthur & Bishop, 2004a).

Acknowledgments

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