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Phonological Processing, Language, and Literacy: A Comparison of Children with Mild-to-moderate Sensorineural Hearing Loss and Those with Specific Language Impairment

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Phonological skills, language ability, and literacy scores were compared for four groups: 19 children with mild-to-moderate sensorineural hearing loss (SNH), 20 children with specific language impairment (SLI), 20 controls matched on chronological age to the SNH group (CA), and 15 controls matched on receptive vocabulary level to a subset of the SLI group (CB). In common with the SLI group, mean scores of children with mild-to-moderate hearing loss were significantly poorer on tests of phonological short-term memory, phonological discrimination, and phonological awareness than CA controls. No differences between group means were observed in SNH and CA control groups on vocabulary, digit and sentence recall, sentence comprehension, and literacy scores. However, there was considerable individual variation within the SNH group. Nearly 50% of the SNH group showed phonological impairment associated with poorer expressive and receptive vocabulary and higher hearing thresholds than remaining children without phonological impairment. Nonword repetition deficits were observed in SNH subgroups with and without phonological impairment and were of a similar magnitude to those observed in children with SLI. Indeed, poorer repetition in children with SLI could only be differentiated from children with SNH on phonologically complex nonwords. Overall, findings suggested major problems in nonword repetition and phonological impairment occurred without clinically significant deficits in wider language and literacy abilities in children with mild-to-moderate sensorineural hearing loss. Implications for theories of SLI are discussed.

Keywords: Hearing loss, language, phonological processing, specific language impairment.

Abbreviations: BPVS: British Picture Vocabulary Scale; CA: control group A; CB: control group B; SLI: specific language impairment; SLI-O: older group of children with SLI; SLI-Y: main SLI group of younger children; SNH: sensorineural hearing loss.

Mastering written and spoken language is one of the most challenging aspects of child development. The ability to segment and discriminate phonemes from incoming speech, as well as acquire knowledge of sound patterns of a language, is important for developing word knowledge. Children with specific language impairment (SLI) whose language has failed to progress normally, despite non-verbal intellect and hearing within the normal range, and children with specific reading disability demonstrate difficulties with discriminating and manipulating phonemes (Bruck, 1992; Catts, 1993; Leitão, Hogben, & Fletcher, 1997; Snowling, Bishop, & Stothard, 2000). There is currently considerable debate as to whether the difficulties seen in these developmental disorders are due to a low-level deficit affecting auditory discrimination, or whether they reflect impairment of a specialised language-processing system.

One recent perspective proposed by Baddeley, Gathercole, and Papagno (1998) is that humans have a specialised memory system for the short-term retention of phonological information that plays a crucial part in the learning of vocabulary and syntax. Phonological short-term memory is considered to impinge on both the acquisition of new words via retention of novel phonological forms, and manipulation of phonological information for wider aspects of language processing such as sentence comprehension. Gathercole and Baddeley (1990) proposed that core limitations in the capacity of phonological short-term memory explain the language learning difficulties of children with SLI. Consistent with this view, children with SLI have substantial difficulties with repeating nonwards, particularly longer nonwords with greater numbers of syllables (Gathercole & Baddeley, 1993, 1996).

An alternative explanation of developmental disorders of language and reading regards such problems as the consequence of low-level auditory perceptual impairments. Such theories have a long history (Eisenson, 1968; Lowe & Campbell, 1965; Tallal, 1976; Tallal & Piercy, 1973), but remain controversial. Thus, while some researchers have demonstrated impairments in discriminating rapid auditory stimuli (Tallal, 1976; Tallal & Piercy, 1973) and enhanced susceptibility to backward masking of auditory stimuli (Wright, Lombardino, King, Puranik, Leonard, & Merzenich, 1997), others have either failed to replicate these findings (Bishop, Carlyon, Deeks, & Bishop, 1999), or else concluded that perceptual impairments are an epiphenomenon, not causally linked

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to the linguistic difficulties experienced by these children (Studdert-Kennedy & Mody, 1995). A central claim of those advocating auditory explanations of SLI is that impaired auditory perception leads to problems in learning the phonological structure of language, with consequent adverse effects on vocabulary acquisition and literacy.

Links between audition, language, and literacy have been explored directly in children with conductive hearing loss associated with otitis media with effusion (Friel-Patti, 1990; Mody, Schwartz, Gravel, & Ruben, 1999; Peters, Grievink, Van Bon, Van den Bercken, & Schilder, 1997). A recent large-scale epidemiological study (Peters, Grievink, Van Bon, & Schilder, 1994) reported only minor effects of otitis media on spelling at 7 years. However, it has been suggested that conductive hearing loss may have adverse effects on language when it occurs in association with other social or health risk factors (Nittrouer, 1996; Peters et al., 1997). Some authors report difficulties with phonological skills despite unimpaired general language skills in children with otitis media (Mody et al., 1999). Mody et al. suggested that otitis media impaired coding of phonologically similar items, i.e. syllable pairs that were differentiated by one, rather than multiple features, into memory.

In contrast to populations of language-disordered children and children with fluctuating hearing loss, scant research attention has been directed to language and literacy development in children with permanent mild-to-moderate hearing loss. Although there is a large body of research documenting the language and literacy outcomes of children with sensorineural hearing loss, most of this focuses on children with severe-to-profound losses that rely heavily on visual information (from lipreading or signed language) to communicate (Quigley & Kretschmer, 1982; Shafer & Lynch, 1981; Schonweiler, Ptok, & Radu, 1998). Much less is known about language and literacy for children with mild or moderate levels of sensorineural hearing loss, even though this might be expected to affect speech perception, because it affects not only hearing level thresholds, but also frequency discrimination for suprathreshold stimuli (Moore, 1995). Standardised academic attainment measures have not detected major deficits in children with mild and moderate hearing loss (Davies, Shepard, Stelmachowicz, & Gorga, 1981). However, delays in vocabulary development have been reported (Blair, Petersen, & Viehweg, 1985; Davies et al., 1981). A study of Gilbertson and Kamhi (1995) was specifically concerned with phonological skills and word learning ability. They found substantial variability in a population of children with sensorineural hearing loss (average reception threshold = 35.35, ranging from 5–65 dB HL) on measures of vocabulary and word learning, as well as word repetition and naming. Indeed, children with hearing loss could be divided into two distinct subgroups: one lower-functioning group with impaired word learning, receptive vocabulary, and general ability, and one with normal language abilities. Indices of phonological skill such as word repetition and rapid naming did not differentiate these subgroups but multisyllabic word repetition was poorer overall in children with hearing loss. Whereas word repetition was directly related to degree of pure tone loss averaged over four to five frequencies, no such relationship was found between novel word learning and degree of hearing loss.

In one of the few studies to compare children with hearing loss and those with SLI, Stollman, Kapteyn, and Sleeswijk (1994) found raised speech reception thresholds (discriminating and producing sentences heard in noise) plus poor recall of digits and sentences for children with either moderate hearing loss or language impairment. Time-compression or time-expansion of sentence stimuli had similar effects on children with SLI and those with moderate hearing loss. The hearing-impaired group did more poorly than the SLI group, however, on a word discrimination task.

This paper reports data from a study comparing children with SLI and children with mild-to-moderate sensorineural loss. Data on mastery of grammatical morphology in the same sample are reported elsewhere (Norbury, Bishop, & Briscoe, 2000). The present paper focuses specifically on phonological skills and literacy. Three indices of phonological skills are considered: (a) ability to discriminate phoneme identity and sequence in pairs of words and nonwords; (b) phonological awareness, using a task where the child has to find the word in a sequence that has the same onset or rime as a target word; (c) nonword repetition. These tasks tap different aspects of phonological processing. The discrimination task required the child to judge if two phonemes differ, or if their sequence differs. In line with Stollman et al.'s (1994) findings, it was anticipated that children with mild-to-moderate hearing loss would have most difficulty with discriminating word and nonword pairs. The SLI group, by contrast, were expected to show difficulties with discriminating nonword pairs in particular, due to the extra demands of segmenting novel speech into phonemes without support from existing lexical representations (see Bishop et al., 1997).

The phonological awareness task, in contrast, involves categorisation of two different auditory events as instances of the same phoneme, i.e. phoneme constancy (Bird, Bishop, & Freeman, 1995). Phoneme constancy relates to variable acoustic correlates depending on the phonemic context in which the same phoneme occurs. Thus the phonetic properties of the sound /p/ will vary depending on which vowel precedes or follows it. Part of the task of language acquisition is to learn to treat these variable manifestations as different exemplars of the same phoneme.

The nonword repetition task is a complex task that requires the child to identify a string of heard phonemes, retain this in short-term memory, and produce the same sequence as speech output. To some extent, the locus of difficulty with the task can be identified by considering how different task variables such as nonword length, complexity, or word "likeness" affect performance. Gathercole and Baddeley (1990) argued that phonological memory is impaired in SLI, because accuracy is generally high on two-syllable sequences in children with SLI but deteriorates sharply as the number of syllables increases (Bishop, North, & Donlan, 1996; Gathercole & Baddeley, 1990). Another factor influencing nonword repetition performance is the extent to which nonwords resemble real words, with better repetition of more "wordlike" nonwords by young children (Dollaghan, Biber, & Campbell, 1995; Gathercole, 1995). Associations between nonword repetition and vocabulary can be seen in typically developing children as young as 3 years (Gathercole, 1995; Gathercole & Adams, 1993). Weaker "wordlikeness effects" on nonword repetition may therefore be observed in children with underdeveloped vocabulary knowledge such as clinical groups. Nonwords rated low in wordlikeness tend to be more strongly associated with vocabulary, rather than wordlike nonwords. Gathercole (1995) interpreted this as critical evidence for the formation of temporary phonological memory representation in nonword repetition, rather than dependence on existing lexical knowledge. Alternatively, Metsala (1999) notes the importance of flexible access to syllables and phonemes for repeating nonwords, particularly low wordlike nonwords. Metsala suggested that the development of vocabulary is critical to enhanced access to syllables and phonemic categories through a process of lexical restructuring: as vocabulary increases so the child shifts from using a "holistic" to a segmentalised representation of spoken words. From this perspective, successful nonword repetition depends on flexible access to a phonemic level: children with larger vocabularies are more able to access syllables and phonemes for repeating unusual patterns of phonemes encountered in nonwords. Thus underdeveloped vocabulary would be expected to reduce common variance between nonword repetition and receptive vocabulary due to reduced lexical segmentation in long-term memory.

Finally, nonword repetition, like other indices of phonological memory such as sentence recall, partly relies on speech output process. This may be particularly salient for explaining nonword repetition deficits in children where speech deficits co-occur with language impairment (Sahlen, Reuterskioeld-Wagner, Nettelbladt, & Radeborg, 1999; Snowling, Chiat, & Hulme, 1991). Speech output processes can be assessed indirectly through the effects of phonological complexity (number of consonant clusters of nonword stimuli) on nonword repetition. Gathercole and Baddeley (1990) did not find any interaction between this variable and group (SLI vs. control), but Bishop et al. (1999) did find a small but statistical significant effect in a larger sample. Overall, the data suggest that while there may be some influence of output factors on nonword repetition in SLI, this is not the principal factor affecting performance. It is predicted that if complexity of nonword stimuli has an effect on children with clinical hearing or language problems, it is likely to be stronger in those children with language difficulties. In the current study we looked at the influence of length (in number of syllables), wordlikeness, and phonological complexity on nonword repetition in two clinical groups: children with SLI, and those with mild-moderate hearing impairment.

Our study addressed the following three questions:

(1) How are phonological discrimination, phonological awareness, and phonological short-term memory influenced by mild-to-moderate hearing impairment in childhood?
(2) Do children with mild-to-moderate hearing impairment resemble children with SLI in the level or pattern of phonological skills?
(3) Are phonological impairments in hearing-impaired children related to other language and literacy attainments?

Method

Participants

Two clinical samples aged from 5 to 10 years were recruited: children with sensorineural hearing loss (SNH) and children with SLI. These children were compared with two control groups of normally developing children. Control group A (CA) were of similar chronological age to the SLI and SNH groups, and control group B (CB) were matched to the SLI group on raw score on a test of receptive vocabulary. In addition, a small group of older children with SLI were included that were matched in vocabulary level to group CA. These are referred to as group SLI-O (old) to distinguish them from the main SLI group of younger children (SLI-Y). All children were from monolingual English-speaking backgrounds and had nonverbal IQs between 80 and 124.

SNH group. Nineteen children aged from 5.91 to 10.66 years (mean age 8.66 years) with bilateral sensorineural hearing impairment were identified via Peripatetic Services for hearing-impaired children in eight regions in South Eastern England. Information about the study and an invitation to participate was distributed to teachers and therapists, who were asked to pass this on to parents of children who (a) had a mild-moderate bilateral sensorineural hearing loss, (b) were attending mainstream school, and (c) did not use sign language. Children whose hearing loss was associated with neurological impairment were excluded from consideration. Three categories of hearing loss were identified in this sample, based on the child's pure tone average (PTA) threshold (in dB HL) in the better ear at 250, 500, 1000, 2000, and 4000 Hz (British Society of Audiology, 1998). *High frequency loss* (three children) was defined as hearing thresholds greater than 25 dB HL at frequencies at or above 2000 Hz, but with PTA of less than 20 dB HL. *Mild hearing impairment* (13 children) was defined as having a PTA of 20–40 dB HL, and *moderate hearing loss* (three children) as having a PTA of 41–70 dB HL. Because our goal was to assess the impact of hearing impairment on language and literacy development, language status was a dependent variable, and not used as a selection criterion for this group. We did, however, note that seven children in the SNH group had received speech and language therapy in the past, but none was currently doing so.

SLI group. Twenty children who met criterion for SLI were included in the present study, from 44 children recruited through three specialist language units in Oxfordshire, England, plus one residential school in Nottingham, England that specialised in the education of children with SLI. To be included in the SLI group, the child had to score below the 10th centile on at least two of four core language measures (see Table 1). Because our goal was to study a homogeneous group of children with typical SLI, we excluded those with evidence of pragmatic language impairment (composite scores of 132 or below on the Children's Communication Checklist; Bishop, 1998). Children with sensorineural hearing loss and those with syndromes associated with language impairment (e.g. Landau-Kleffner syndrome, Asperger's syndrome) were also excluded. Furthermore, to avoid complications of interpreting nonword repetition data from children with poorly intelligible speech, children who achieved less than 80% consonants correct in a phonology screening test were excluded. As noted above, most of these children ($N = 14$) were in the same age range as the SNH group (mean age = 8.96, range = 7.20–10.91) and will be referred to as the SLI-Y subgroup. In addition, we studied a small subgroup of older children who formed the SLI-O group ($N = 6$; mean age = 12.11, range = 11.89–13.0). The SLI groups did not differ from the SNH group in nonverbal IQ.

Control groups. Thirty-five control children with no known educational difficulties or history of speech and language therapy were recruited mainly from primary schools in the Oxfordshire area. Several control children were also selected randomly from classrooms of hearing impaired participants. Twenty children formed a chronological age control group (CA controls: mean age = 8.49, range = 5.60–10.77 years). Fifteen younger children were matched to within 3 months of the receptive vocabulary level of children from the SLI-Y group to form a language-matched control group (CB: mean age = 7.40, range = 4.97–9.17 years). Inclusion of a language-matched control group enables us to see whether any phonological impairments seen in the SLI group are in line with their overall level of language functioning. The mean raw score on the

Table 1
Standardised Assessments Used in the Study

Assessment	Domain	Brief description of task
Raven's Coloured Progressive Matrices (Raven, 1986)	Nonverbal reasoning	Select one of six items to complete a pattern
*British Picture Vocabulary Scales: BPVS (Dunn, Dunn, Whetton & Pintilie, 1982)	Receptive vocabulary	Select one of four pictures to match a word spoken by examiner
*Test for Reception of Grammar: TROG (Bishop, 1989)	Understanding of grammatical contrasts	Select one of four pictures to match spoken word, phrase, or sentence
*Recalling Sentences subtest from Clinical Evaluation of Language Fundamentals-Revised (Semel, Wiig, & Secord, 1987)	Sentence memory	Repeat spoken sentences of increasing length and complexity
*Children's Test of Nonword Repetition: (Gathercole & Baddeley, 1996)	Phonological short-term memory	Repeat 40 nonwords that are presented on audiotape
Word finding test (three subscales) (German, 1989)	Expressive vocabulary	Name pictured noun, verb, or category
(a) Basic Reading and (b) Reading Comprehension subtests of Wechsler Objective Reading Dimensions (Rust, Golombok, & Trickey, 1993)	Reading ability	(a) Read aloud single words (b) Answer questions about short written passages
Graded Nonword Reading Test (Snowling, Stothard, & Mclean, 1996)	Literacy/decoding skills	Read aloud written nonwords

*Denotes a core language measure used in the criteria for SLI.

British Picture Vocabulary Scale-long form (BPVS) for group CB was 71.2 ($SD = 16.56$), compared with a mean of 68.8 ($SD = 16.37$) for group SLI-Y. In addition, group CA were well matched to group SLI-O on the BPVS (mean raw score for group CA = 87.1, $SD = 14.64$; mean for group SLI-O was 88.0, $SD = 6.87$).

Procedure

Each child was administered a battery of linguistic and nonverbal measures of ability in two test sessions that lasted approximately 45 minutes each. Children were tested individually in a quiet area of their school by a single experimenter.

Assessments. Standardised assessments, including the four core linguistic measures, are described in Table 1. With the exception of nonword repetition and word finding, scores on these tests were transformed to standard scores according to published norms (mean = 100, $SD = 15$, except for recalling sentences, where mean is 10, $SD = 3$). For nonword repetition, published norms extend only to 9 years. Furthermore, the published norms gave low standard scores to control children in this sample, despite their normal performance on other tests. This could be because children's responses were transcribed phonetically from tape by an experienced speech and language therapist, whereas the published norms are based on on-line scoring, which may be less sensitive to mispronunciations. Normative data from a study by Bishop et al. (1996) gave standard scores more in line with expectation for control children, and extended the normative database up to 13 years. Where both sets of norms could be applied, two standard scores were computed, and the mean taken. Otherwise, norms were derived from the dataset that covered the child's age. Norms are not available for individual subtests of the German Word Finding Test. Accordingly, we used data from the combined control groups (CA and CB) to estimate the regression of total correct on age, and used this equation to compute age-scaled scores for all children, based on mean of 100 and SD of 15.

In addition to the standardised tests, experimental tests of phonological skills and short-term memory were administered.

Phonological discrimination of alveolar stops and fricatives was examined using a task developed by Bridgeman and Snowling (1988). The child was presented with pairs of words or nonwords, and asked to say if they were the same or different. Items were presented in a single block of 60 trials with 24 trials differing by final feature (/s/ or /t/, e.g. "guess" vs. "get"), 24 trials that differed by phoneme sequence in word final position (/st/ vs. /ts/, e.g. ("lest" vs. "lets"), and 12 trials where the pair was identical. The score was the percentage of items correct.

Phonological awareness was assessed using a method derived from Bird, Bishop, and Freeman (1995) to evaluate children's ability to match words on the basis of rime or onset. Children were presented with a picture of a named monster, e.g. Dan, and were told that the monster liked "things that sounded like his name". The task was to select one of four picture cards to give to the monster. The experimenter named each picture, and practice trials with feedback were given to ensure the child understood the task. Onset matching was conducted in a similar way, with children told to find the pictured object that had the "same beginning sound" as the monster's name, e.g. "duck" for "Dan". Three trials were presented for six different monsters, giving nine trials for rime matching and nine for onset matching. The score was the percentage of items correct.

Expressive phonology was assessed using a screening test that required the child to name pictured items covering a wide range of speech sounds. We used a 25-word list, derived from the Inconsistency Test (Dodd, 1995). Children's productions were tape-recorded for broad phonological transcription by an experienced speech and language therapist. For the current paper, we report only data on percentage of words produced without error.

Digit recall was assessed by having the child repeat lists of two to eight numbers that were spoken at a rate of one per second, following the procedure adopted by Briscoe, Gathercole, and Marlow (1998). If the child achieved four out of five possible correct repetitions at a given list length, the next list length was administered, otherwise testing was discontinued. The score was the number of lists repeated correctly.

Results

Descriptive statistics for standardised tests of nonverbal and language ability are presented for the SNH and SLI groups, plus control children in Table 2. Univariate ANOVAs confirmed a main effect of group on all measures: BPVS: $F(4, 69) = 12.5$, $p < .001$; recalling sentences; $F(4, 67) = 42.4$; $p < .001$, nonword repetition: $F(4, 68) = 24.9$; $p < .001$, Test for the Reception of Grammar (TROG): $F(4, 69) = 6.6$; $p < .001$, word finding: $F(4, 67) = 14.2$; $p < .001$. Scheffé tests set at $p < .05$ confirmed that the two SLI groups differed from

Table 2
Mean (SD) of Age and Standard Scores on Standardised Tests of Language and Cognition

	SNH (N = 19)	SLI-Y (N = 14)	SLI-O (N = 6)	CA (N = 20)	CB (N = 15)
Age (years)	8.66 (1.36)	8.96[b] (1.15)	12.12[ab] (0.44)	8.49 (1.55)	7.40 (1.26)
Raven's Matrices	109.79 (14.07)	105.43 (14.15)	95.33 (7.89)	107.35 (12.84)	104.80 (7.67)
BPVS	98.63 (16.22)	85.93[ab] (12.10)	83.17[ab] (7.19)	110.15 (7.87)	103.20 (8.89)
TROG	108.26 (18.72)	88.29[a] (12.98)	93.67 (10.54)	112.90 (16.16)	100.20 (12.00)
Recalling sentences	8.79 (3.38)	3.86[ab] (0.77)	3.33[ab] (0.52)	12.95 (2.04)	10.69 (2.36)
Nonword repetition	64.05[ab] (14.94)	60.50[ab] (9.02)	55.00[ab] (0.00)	98.74 (16.51)	83.47 (15.17)
Word finding	91.8 (12.42)	73.2[ab] (13.28)	69.5[ab] (8.27)	103.1 (10.31)	96.3 (18.50)

[a] Significant difference from group CA on Scheffé test at $p < .05$.
[b] Significant difference from group CB on Scheffé test at $p < .05$.
Planned comparisons between SNH and SLI groups are described in the text.

Table 3
Mean (SD) Age and Standard Scores on Standardised Tests of Literacy

	SNH (N = 19)	SLI-Y (N = 14)	SLI-O (N = 6)	CA (N = 20)	CB (N = 15)
Word reading	106.56 (14.28)	76.00[ab] (9.23)	64.83[ab] (7.05)	110.74 (16.56)	101.46 (10.98)
Reading comprehension	100.22 (13.17)	74.14[ab] (10.16)	57.83[ab] (11.46)	109.95 (10.51)	100.69 (17.49)
Nonword reading	98.11 (14.61)	77.57[ab] (13.12)	70.33[ab] (0.52)	107.95 (14.13)	101.38 (10.06)

[a] Significant difference from group CA on Scheffé test at $p < .05$.
[b] Significant difference from group CB on Scheffé test at $p < .05$.
Planned comparisons between SNH and SLI groups are described in the text.

both control groups on three of the four linguistic tests known to be sensitive to language impairment (BPVS, recalling sentences, nonword repetition), whereas on the TROG the only significant difference was between SLI-Y group and their age-matched controls. Both SLI groups also showed marked deficits on word finding compared to both control groups. Deficits on the core language tests are to be expected for the SLI groups, given our selection criteria. It is worth noting that, although children could be included in the SLI group for scoring below the 10th centile on any two of the core language tests, in practice, the tests were differentially sensitive. All children with SLI were impaired on recalling sentences, and all but one on nonword repetition. Eight were impaired on BPVS, and only three on TROG.

As indicated by Scheffé tests in Table 2, children in the SNH group showed a very different pattern of performance. On only one test, nonword repetition, did they resemble the SLI groups, and perform significantly more poorly than control children. On all the other language tests they did not differ significantly from control children, and on two language measures (recalling sentences and word finding) they performed significantly better than both of the SLI groups. However, mean scores on language tests masked wide individual variation within the SNH group: four children from this group (one of whom had no history of speech and language therapy) met our criteria for language impairment, i.e., scoring below the 10th centile on two of the four core language measures (in two cases, the impairment was in nonword repetition and BPVS, and in two it was in nonword repetition and recalling sentences).

Table 3 shows performance on measures of literacy for SNH and SLI children, plus control children. Univariate ANOVAs indicated main effects of group on measures of literacy: basic reading: $F(4, 65) = 25.91$; $p < .001$; reading comprehension: $F(4, 65) = 29.83$; $p < .001$; nonword reading; $F(4, 67) = 18.08$; $p < .001$. Scheffé tests set at $p < .05$ showed marked deficits for both SLI groups compared to control groups on all three measures of literacy. In contrast, children in the SNH group did not differ from control children, and performed significantly better than both SLI groups.

Analysis of Phonological Discrimination Task

Overall performance on phonological discrimination was scored as percentage items correct. Data were strongly skewed with ceiling effects in the CA group. A nonparametric Kruskal–Wallis test confirmed an overall difference across groups, $H(4) = 20.4$, $p < .001$. Differences between groups were investigated with planned comparisons using Mann–Whitney tests. Both SLI-Y and SLI-O groups were found to differ significantly from CA controls (ps $< .001$). The SNH group also performed more poorly than CA controls ($p < .001$) and there was no statistical difference between the scores of the SNH and the SLI-Y groups.

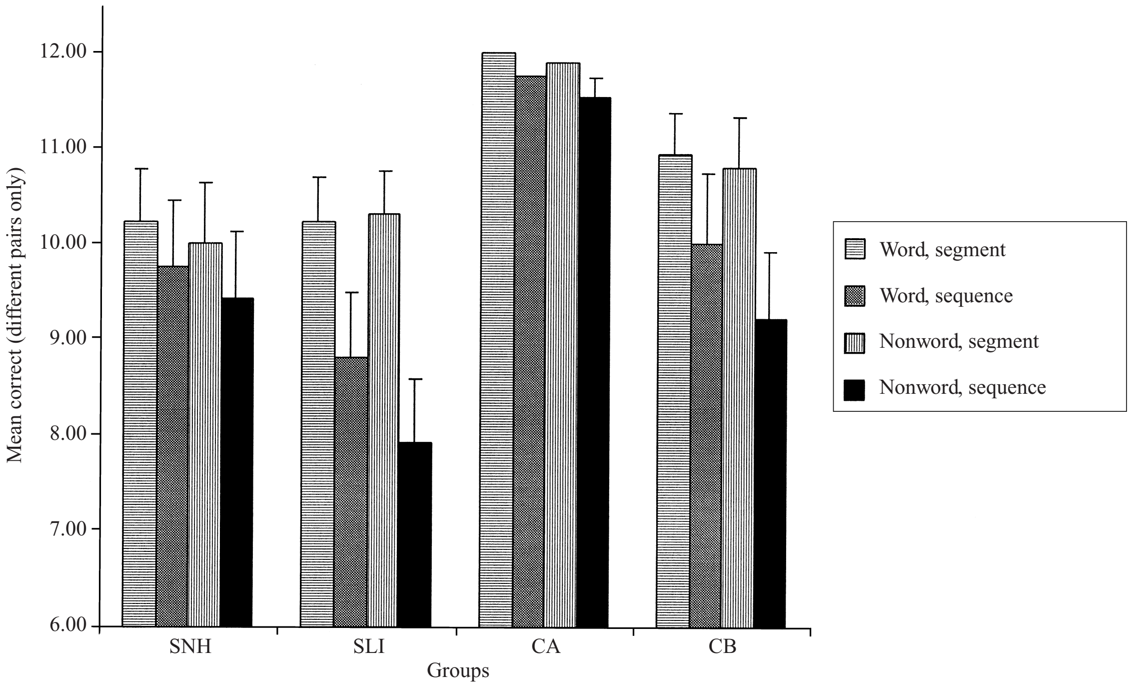

Figure 1. Mean scores on phonological discrimination task by four groups in relation to item type. Error bars show standard errors.

Since older and younger SLI groups did not differ on their overall percentage correct, these groups were combined for further analysis of this task. In order to check whether response bias differed across groups, preliminary analysis of "same" items was conducted across four groups (SNH, CA, CB, and combined SLI). All four groups obtained similar mean totals for "same" items correct out of 12: SNH = 10.3, CA = 11.0, CB = 10.8, combined SLI = 10.7; $F(3, 70) = 0.056$, $p = .64$. Figure 1 shows performance on "different" items across the four groups, split by lexical status and segment/sequence change.

Because the CA group performed at ceiling, a three-way ANOVA was conducted on groups SNH, CB, and combined SLI, with lexical status and segment/sequence change as within-subject factors. On the basis of the findings of Stollman et al. (1994), we had anticipated that the SNH group would be most impaired on this task. Furthermore, we predicted that children with SLI might do disproportionately poorly with nonword stimuli, which cannot be matched to existing lexical representations, and may be difficult to segment into phonemes (cf. Bishop, 1997). However, neither prediction was confirmed. Both lexical status and segment/sequence significantly affected performance across groups, $F(1, 51) = 6.23$, $p = .016$ and $F(1, 51) = 23.17$, $p < .001$, respectively. There was no main effect of group and no interactions with group reached significance. As seen in Fig. 1, there was a nonsignificant trend for the combined group SLI to do disproportionately poorly on items that varied phonological sequence.

Analysis of Phonological Awareness and Expressive Phonology Tasks

Scores on the phonological awareness and expressive phonology measures were expressed as percentage items correct for the five groups of children (SNH, SLI-Y, SLI-O, CA and CB groups). Again, data were strongly skewed, with group CA showing ceiling effects on both measures. Kruskal–Wallis nonparametric analyses indicated significant differences across groups on the phonological awareness task, $H(4) = 13.57, p < .01$, and expressive phonology measure, $H(4) = 24.43$, $p < .001$. To determine the nature of differences between groups, planned comparisons of both SLI groups with SNH and CA groups were conducted. Whereas group SLI-Y (phonological awareness mean = 80.6, $SD = 22.1$; expressive phonology mean = 80.6, $SD = 14.4$) obtained significantly poorer scores than group CA (phonological awareness mean = 97.5, $SD = 6.4$; expressive phonology mean = 97.8, $SD = 4.5$) on both measures ($ps < .001$), group SLI-O differed significantly from group CA only on expressive phonology (SLI-O mean = 77.0, $SD = 24.6$, $p < .01$), but not phonological awareness (SLI-O mean = 97.2, $SD = 6.8$). The children with SNH were poorer than group CA on phonological awareness (SNH mean = 90.6, $SD = 13.7$, $p = .021$). Additional comparisons using Mann–Whitney tests confirmed that group SNH differed from group SLI-Y only on the test of expressive phonology (SNH mean = 93.3, $SD = 9.4$, $p < .01$).

Analysis of Digit Span and Nonword Repetition Tasks

Scores on the digit span test were normally distributed across all five groups. One-way ANOVA showed a significant overall group effect, $F(4, 69) = 5.87$, $p < .001$). Additional Scheffé tests (alpha level set at $p < .05$) confirmed that the only pairwise group comparisons to reach statistical significance were that between group SLI-Y (mean = 11.9, $SD = 2.95$) and group CA (mean = 17.4, $SD = 4.55$), and that between group SLI-O (mean = 11.8, $SD = 3.06$) and group CA. Group SNH (mean = 15.0, $SD = 3.38$) did not differ significantly from group CA.

In Table 2, we saw that the SNH group resembled the SLI groups in terms of absolute level of performance on

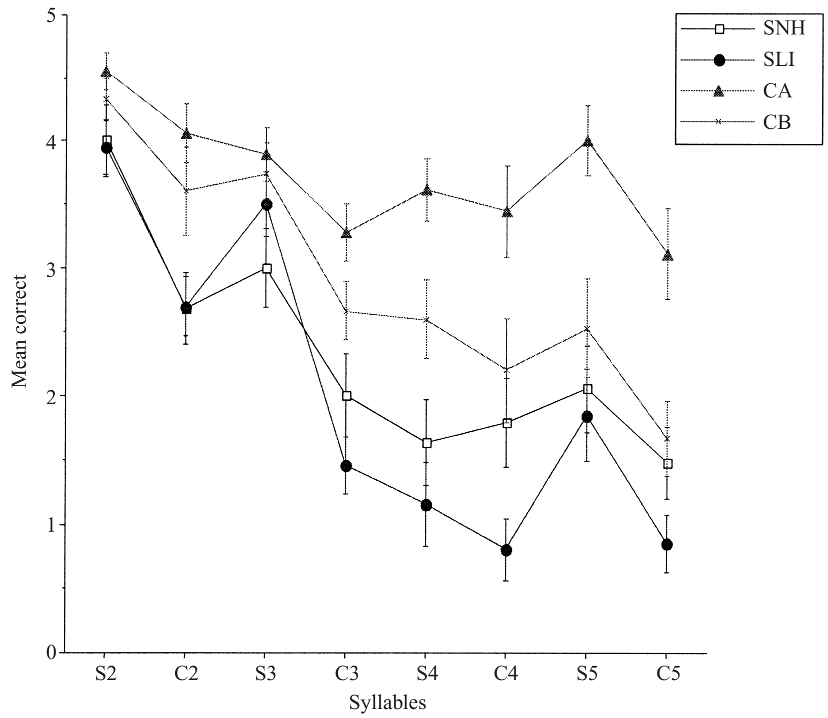

Figure 2. Nonword repetition mean scores for four groups in relation to number of syllables (range two- to five-syllable) and phonological complexity (S = simple, C = complex). Error bars show standard errors.

the nonword repetition task. This raises the question of whether qualitative aspects of performance were the same. As Table 2 indicated, the level of performance in both the SLI-Y and SLI-O groups did not appear to differ on overall accuracy on nonword repetition, based upon age-scaled scores. Neither age-scaled scores, t (18) = 1.47, $p = .16$, nor absolute total correct scores, t (18) = 0.71, $p = .49$, on nonword repetition were found to differ between older and younger SLI groups, $ps > .05$. These two groups were then combined (SLI) to increase power in qualitative analysis on nonword repetition abilities. This combined SLI group was contrasted with all other groups (SNH, CA, and CB) in a three-way ANOVA with length (N syllables) and phonological complexity (presence/absence of consonant clusters) as within-subjects factors. All main effects: group: F (3, 68) = 17.1; length: F (3, 204) = 66.4; complexity: F (1, 68) = 107.1; and two-way interactions: group by length: F (9, 204) = 3.6; group by complexity: F (3, 68) = 3.3; length by complexity: F (3, 204) = 7.6; were significant at the .01 level. Figure 2 indicates scores for SNH, combined SLI, CA, and CB groups on each of the eight conditions (simple and complex nonwords at two, three, four, and five syllables). Nonword repetition accuracy scores across groups for simple and complex nonwords at each syllable length were compared using Fisher's protected LSD method. All pairwise comparisons were significant at the .05 level, apart from comparison of the SNH and combined SLI groups.

In order to replicate previous interaction effects of SLI with length and complexity of nonwords in the repetition task (Bishop et al., 1996), the combined SLI group and CA control group were compared on each of the eight conditions. Post hoc Scheffé tests (with p set to .006 to adjust for multiple comparisons) showed that the SLI children differed significantly from controls on all except the phonologically simple nonwords of two or three syllables. The interaction of group with N syllables was explored directly by computing the slope of the function relating N syllables to total correct for each child. The slope was significantly more shallow for group CA (mean = −0.46, SD = .909) than for combined group SLI (mean = −1.35, SD = 1.02); t (36) = 2.83, $p = .008$. The interaction of group with complexity was explored by computing the number of complex nonwords correct as a proportion of simple nonwords correct for each child. The mean values were .868 (SD = .166) for group CA, and .539 (SD = .204) for combined SLI group; t (36) = 5.41, $p < .001$. Together these findings show that children with SLI do not differ on the ability to repeat short, simple nonwords, but they were significantly less able to repeat longer and more phonologically complex nonwords than age-matched controls. Of particular interest here was whether qualitative differences could be observed between SNH and combined SLI groups.

As noted above, there was no statistical difference between SNH and combined SLI groups on either standard scores (see Table 2) or absolute total correct scores (see Fig. 2). A one-way ANOVA with N syllables and complexity was conducted on these two groups alone. Only the interaction between group and phonological complexity reached significance, F(1, 111) = 4.85, $p = .034$. By computing the score for complex nonwords as a proportion of the score for simple nonwords, it was clear that the combined SLI group were significantly poorer than the SNH group (mean = .740, SD = .279) on the repetition of phonologically complex nonwords only, t (37) = 2.58, $p = .014$.

In sum, children with SLI and children with SNH show similarities and differences in performance on two tasks considered to reflect aspects of phonological short-term memory performance (Gathercole & Baddeley, 1993). Both groups showed a marked reduction in repetition of longer nonwords, and similar absolute levels of repetition performance. However, children with SLI were additionally impaired on digit recall, and were more adversely affected by phonologically complex nonwords compared to the SNH group. Since stored word knowledge facilitates memory for nonwords, and children with SLI have weak receptive vocabulary (see Table 2), it was of interest whether lexical knowledge was related to nonword repetition performance in these clinical groups.

Analysis of Nonword Repetition and Word Knowledge

A subset of nonwords, previously rated "high" and "low" in wordlikeness (Gathercole, 1995), were subject to a two-way ANOVA with group (combined SLI, SNH, CA, and CB) and wordlikeness as the within-subjects factor. Main effects of group, $F(3, 65) = 16.27$; $p < .001$, and wordlikeness, $F\ (1, 67) = 24.43$; $p < .001$, were statistically significant, and there was no significant interaction, $F\ (3, 65) < 1$. Nonwords that were highly wordlike were repeated more accurately (mean = 8.47) than those low in wordlikeness (mean = 7.03), but this effect was equivalent across all groups.

The nature of the relationship between nonword repetition (total correct scores) and receptive and expressive vocabulary (BPVS raw scores and word finding total correct scores respectively) was also examined. SLI (young and old), plus control groups (CA and CB) were combined for additional power in correlational analyses. Both control and SNH groups showed significant relationships between repetition accuracy of high wordlike nonwords and receptive vocabulary, SNH $r\ (19) = .52$ and control $r\ (34) = .62$; ps $< .05$, as well as high wordlike nonwords and expressive vocabulary, SNH $r\ (19) = .53$ and control $r\ (34) = .37$; ps $< .05$. Similarly, repetition accuracy of low wordlike nonwords was significantly related to receptive vocabulary, SNH $r\ (19) = .62$ and control $r\ (34) = .63$; ps $< .05$, and expressive vocabulary, SNH $r\ (19) = .52$ and control $r\ (34) = .39$; ps $< .05$, in both groups. Repetition accuracy was not significantly correlated with receptive vocabulary; "high" wordlike nonwords, $r\ (20) = .12$; $p > .05$; "low" wordlike nonwords, $r\ (20) = .17$; $p > .05$; or expressive vocabulary; "high" wordlike nonwords, $r\ (20) = .25$; $p > .05$; "low" wordlike nonwords, $r\ (20) = .24$; $p > .05$, in the combined SLI group. The specificity of the nonword repetition-vocabulary relationship was investigated further by removing variance associated with age in each group. Once age-related variance was removed, there was a significant relationship between repetition accuracy of low wordlike nonwords and receptive vocabulary, partial $r\ (31) = .43$; $p < .05$, in the combined control group, plus marginal significance in the SNH group, partial $r\ (16) = .42$; $p = .07$. There were no significant partial correlations between low wordlike nonwords and expressive vocabulary in either group: SNH partial $r\ (16) = .21$, control partial $r\ (29) = .12$, n.s., or any significant relationships between high wordlike nonwords and vocabulary scores once age-related variance was removed in any group. So, despite overall similarities in the level of nonword repetition deficit in the SLI and SNH groups, the SLI group did not show the overlap between nonword repetition accuracy scores and receptive vocabulary scores as seen in the other groups.

Thus far, it has been shown that the SLI and SNH groups differ in their profile of performance across language, literacy, and phonological tasks. Whereas the SLI groups show generalised impairment across all measures, the SNH group show selective impairment on phonological measures that include phonological discrimination, phonological awareness, and nonword repetition.

Correlates of Variation within the SNH Group on Phonological Tasks

So far, the focus of this paper has been the analysis of group means, but, as noted earlier, there was substantial variation in the SNH group. This raises two further questions of particular interest.

(1) To what extent are factors such as severity of hearing loss, age of diagnosis of hearing loss, or general cognitive ability associated with phonological deficits in children with SNH?
(2) Is phonological impairment associated with other measures of language impairment in the SNH group?

Subsequent investigation focused upon establishing subgroups of children with hearing loss with or without phonological impairment to examine factors associated with phonological impairment.

To consider correlates of variation on phonological tasks in the SNH group, children were reclassified according to whether they had major impairments on phonological tasks, as evidenced by scores below the 10th centile on two or more of the following: nonword repetition, expressive phonology, phonological discrimination, and phonological awareness. For nonword repetition, the cutoff was a scaled score of 80 or below. For the other nonstandardised tests, where distributions of scores in the control groups were skewed, cutoffs were determined by subdividing the combined control groups into 17 children aged between 5 and 7 years, and 18 children aged 8 and above, and determining a cutoff that selected the lowest 2 control children within each age band. Cutoffs for older and younger controls respectively were as follows: phonological discrimination: 93% and 65%; phonological awareness, 100% and 80%; expressive phonology, 96% and 78%. The numbers of children meeting criteria for phonological impairment were as follows: SNH, 9 out of 19 (47%); SLI combined group, 17 out of 20 (85%); CA, 0 out of 19; CB, 2 out of 15 (13%).

A t-test revealed no significant difference in age between those in the SNH group with and without phonological impairments: unimpaired, mean = 8.78 years, $SD = 1.33$; impaired, mean = 8.53 years, $SD = 2.17$; $t\ (17) = 0.39$, $p = .705$. The two subgroups did not differ significantly on nonverbal reasoning as assessed by Raven's matrices: unimpaired, mean = 113.0, $SD = 12.33$; impaired, mean = 106.2, $SD = 15.71$; $t\ (17) = 1.05$, $p = .308$. Nor did the two groups differ on age at diagnosis of hearing loss: 49.2 months, $SD = 19.37$ for those without phonological impairments; 47.1 months, $SD = 20.59$, for those with phonological impairments. The groups did differ significantly, however, in severity of hearing loss. The mean thresholds at each frequency are shown in Fig. 3. Two-way ANOVA gave a significant effect of subgroup, $F\ (1, 17) = 7.56$, $p = .014$, but no interaction between subgroup and frequency, $F(4, 68) = 0.29$, $p = .280$.

Analysis of means suggested there is a dissociation within the SNH group between impaired phonological

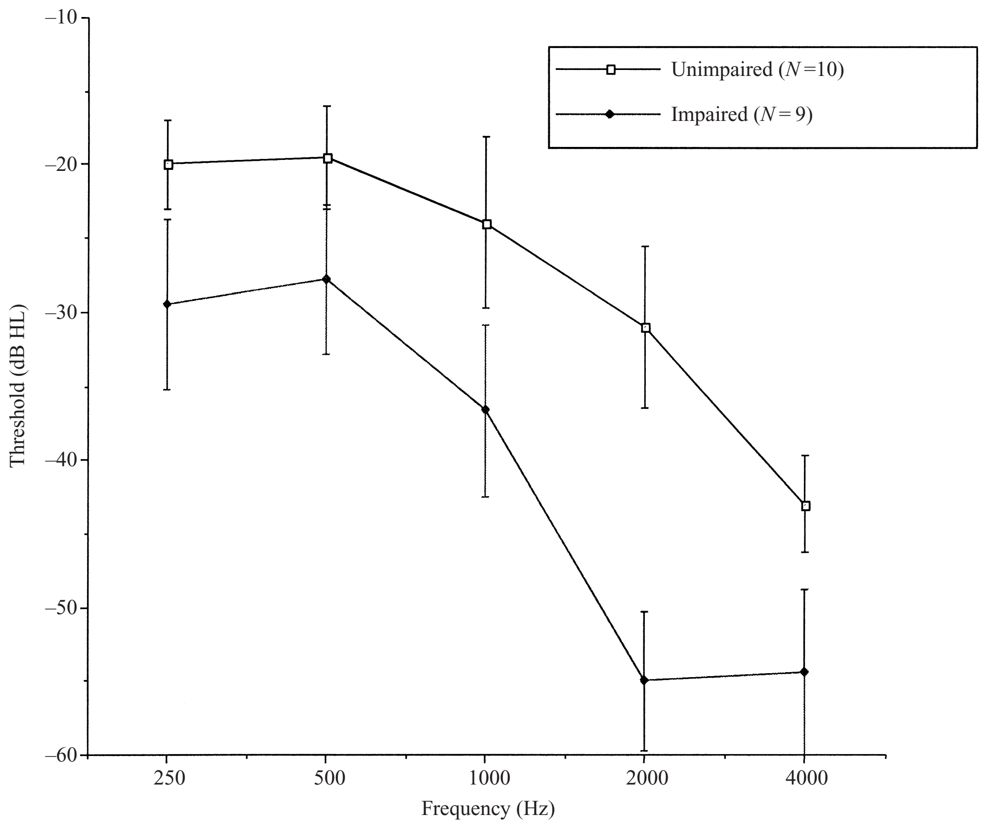

Figure 3. Hearing thresholds in relation to phonological impairment status in SNH group. Error bars show standard errors.

Table 4
Language and Literacy Mean Scores (SD) for SNH Subgroups with and without Phonological Impairment

	Phonological status					
	Unimpaired ($N = 10$)		Impaired ($N = 9$)		t	p
BPVS	109.5	(11.54)	86.6	(11.41)	4.35	< .001
TROG	113.6	(17.28)	102.3	(19.43)	1.34	.198
Recalling sentences	10.2	(3.62)	7.2	(2.39)	2.09	.052
Word finding	98.2	(9.32)	84.6	(11.89)	2.77	.013
Word reading	112.2	(13.63)	99.5	(12.41)	2.04	.058
Reading comprehension	104.2	(14.49)	95.3	(10.03)	1.48	.158
Nonword reading	104.0	(11.98)	91.6	(15.07)	2.00	.061
Digit span	14.7	(3.40)	15.3	(3.54)	−0.40	.695

Scores are scaled scores with mean 100, *SD* 15, except for recalling sentences (scaled with mean 10, *SD* 3), and digit span (raw score).

skills and relatively intact language and literacy. However, a more stringent test is to perform a within-group comparison of language scores for children who do and do not have evidence of phonological impairment within the SNH group. Relevant data are shown in Table 4. This shows the trend for the subgroup with phonological impairment to do more poorly on all measures except digit span. This reaches significance only for the two vocabulary measures, BPVS and word finding. Impaired phonological skills in children with hearing loss overlap with impairment in some aspects of language, notably vocabulary. Nevertheless, in children with hearing loss, phonological impairment is not linked to large-scale problems in language and literacy, beyond deficits in vocabulary knowledge.

Performance on nonword repetition was of particular interest. It was anticipated that the SNH subgroups would differ on this measure, which was one of the tests used to identify phonological impairment. However, even those children with SNH who did not meet criteria for phonological impairment tended to do as poorly on this one test as those who were classed as phonologically impaired. Furthermore, the means of both these subgroups did not have standard scores in the normal range, were significantly poorer than those of the CA control group ($p < .01$), and did not differ from the SLI group. It is clear that severe deficits in nonword repetition, which have been seen as a hallmark of heritable SLI (Bishop et al., 1996), can occur in the context of hearing impairment without other major difficulties in language and literacy.

Discussion

The principal finding from this study is that children with mild-to-moderate sensorineural hearing loss are as impaired as normally hearing children with SLI on tests of phonological discrimination, phonological awareness, and nonword repetition, yet they do not show the pervasive difficulties with language and literacy that characterise SLI. Interpretation of our data is complicated by the wide variation seen in the hearing-impaired group, and it is important not to rely solely on mean scores when interpreting their data. A more complete picture was given by subdividing the SNH group into those who were impaired (below 10th centile) on two or more indicators of phonological impairment. The "unimpaired" group tended to be those with milder hearing losses. Despite their designation as unimpaired, they showed pronounced deficits on one phonological measure, nonword repetition. However, as is evident in Table 4, this was an isolated impairment, and other language and literacy skills were well within normal limits.

Close scrutiny of the subgroup of hearing-impaired children classed as phonologically impaired suggests language and literacy skills tend to be poorer than those of the phonologically unimpaired subgroup, but nevertheless, there are few significant differences. One would not want to place too much weight on this lack of difference, given the small sample size and corresponding low statistical power. However, the impression of relative lack of impairment is strengthened when these scores are considered both in relation to test norms, and in relation to the scores of children with SLI (see Table 2). Mean scaled scores for the "impaired" SNH subgroup are well within normal limits for TROG, word reading, reading comprehension, and nonword reading, and around 1 *SD* above that of the SLI group for recalling sentences and word finding. Receptive vocabulary is the notable exception, with the impaired SNH group obtaining a score around 1 *SD* below the normative mean, close to that seen in children with SLI.

It was anticipated that children with hearing impairment might show phonological impairments similar to those seen in SLI, as indeed we found. However we had expected a close link between phonological impairment and other language and literacy measures, and this was not found. There was no evidence of any language or literacy problem in the subset of hearing-impaired children who had isolated impairments on nonword repetition, and only vocabulary deficits in the remainder. It thus appears that phonological problems that are tightly linked to language and literacy difficulties in normally hearing children can be dissociated from other language skills in the hearing impaired. Two possible lines of explanation suggest themselves. First, it is possible that the nature of the phonological problems is different in the two groups, so that the superficially similar test scores mask important differences in underlying processes. Second, it may be that phonological problems are a necessary but not sufficient cause of SLI, and that additional cognitive impairment must be present for major language difficulties to result.

We sought evidence for qualitative differences between SNH and SLI groups in phonological problems by considering how task variables affected performance. The pattern of performance on nonword repetition in the SLI and SNH groups was considered to see whether different underlying mechanisms may be responsible for poor performance in the two groups. In particular, it seemed likely that poor nonword repetition in the SNH group might simply reflected poor discrimination of speech sounds, and so is apparent on short as well as long nonwords. This, however, was not the case. Both SLI and SNH groups performed close to age-matched controls on short nonwords but showed a sharp fall-off in nonword repetition ability with number of syllables in the nonword. This pattern of performance has been interpreted by Gathercole and Baddeley (1990) as evidence for storage limitations in phonological short-term memory. However, storage limitations were not evident on digit recall in the SNH group: a finding that questions the interpretation of these measures as indicators of similar processes of phonological working memory, and offers some clues as to what might differentiate SNH from SLI. It is possible that children with SLI have some intrinsic limitation of memory capacity that is evident with a wide range of material, whereas those with SNH have normal memory capacity, but this is taxed when struggling to process novel sound sequences through an impaired auditory system.

Within the nonword repetition task, the only qualitative difference observed was that the SLI group were more adversely affected by phonological complexity than the other groups. This replicates previous work by Bishop et al. (1996), although Gathercole and Baddeley (1990) did not observe this effect. Although phonological complexity effects have usually been interpreted as due to articulatory programming limitations, they could also reflect perceptual limitations in processing the phonological substrate of complex consonant clusters (such as coarticulatory cues). The difficulty may be not so much one of telling sounds apart, but in acquiring a phonemic level of analysis when analysing unfamiliar speech (Edwards & Lahey, 1998). If the child processes incoming speech in terms of syllables or clusters of consonants, rather than individual phonemes, there may be awareness that the input contains features such as frication or nasality, but uncertainty as to where exactly these features occur. The data from the phoneme discrimination task lend some support to this kind of account, insofar as the SLI group showed a trend for disproportionate difficulty in distinguishing consonant clusters differing only in sequence. However, it remains an open question whether increasing vocabulary knowledge drives access to phonemic representation (Metsala, 1999), or whether children utilise a perceptual strategy that enables them to "learn to listen" to phonemic categories.

One other way in which the SLI group differed from other children was in the failure to show any association between nonword repetition and vocabulary knowledge, replicating previous findings (Edwards & Lahey, 1998). This contrasts with the SNH group, who had comparable magnitude of nonword repetition deficit to the SLI group, but who showed some association between vocabulary and nonword repetition. Receptive, rather than expressive vocabulary tended to correlate more strongly with nonword repetition in the SNH and control groups. Common variance between receptive vocabulary and low wordlike nonwords may be explained by segmentalised structure in long-term memory (Edwards & Lahey, 1998; Metsala, 1999). This may explain the lack of correlation between these measures in the SLI group. However, one might wonder whether children with SLI fail to draw on lexical knowledge when repeating novel material, but if this were so then we would not expect to see a wordlikeness effect in this group. In fact, a clear effect of wordlikeness was found for all groups.

Overall, then, qualitative analysis of performance on phonological tasks does not reveal any striking differences between children with SLI and those with SNH, although there is a hint that difficulties in encoding novel speech at the phonemic level may be more of a problem for those with SLI, and there is a puzzling lack of association between nonword repetition ability and vocabulary knowledge in this group. Overall, however, the profiles of children with SNH and those with SLI were similar on phonological tasks, and, in particular, both groups showed a pattern of performance on the nonword repetition task that suggested impaired storage in phonological short-term memory.

What does this tell us about the role of phonological processing in normal and impaired language acquisition? There does seem to be a link between impairments in phonological discrimination and awareness on the one hand, and vocabulary acquisition on the other. However, there is no necessary relation with other language abilities, nor with literacy. In this regard, our findings agree with those of a single case study by Stothard, Snowling, and Hulme (1996), who reported a child with the phonological deficits characteristic of dyslexia but who could read adequately. Similarly, recent reports from children with mild to moderate fluctuating loss associated with otitis media indicate subtle phonological processing problems in the absence of major language impairment (Mody et al., 1999). Our findings further suggest that although auditory deficits could plausibly be at the root of some of the phonological impairments seen in SLI children, they do not fully account for the whole gamut of language and literacy difficulties seen in this population. One possibility, mooted by Bishop et al. (1999), is that SLI is the consequence of a constellation of risk factors. Most theoretical accounts of SLI postulate a single underlying deficit to explain the whole range of language difficulties. While this is parsimonious, it may be inaccurate. Language development may be so robust that it only suffers badly if subjected to a "double hit" of cognitive deficits. The current study suggests that auditory deficit can compromise phonological skills, especially phonological short-term memory, but this does not invariably lead to serious impairments in verbal memory or literacy. It may be, however, that when phonological problems coexist with other cognitive limitations, more serious language deficits ensue. The striking deficits shown by children with SLI on tests of short-term memory for meaningful material (digits or sentences) contrasts starkly with the performance of group SNH, and suggests that some kind of processing capacity limitation (see Leonard, 1998) may be critical in causing the language deficits of children with SLI.

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