Lexicality and Frequency in Specific Language Impairment: Accuracy and Error Data from Two Nonword Repetition Tests

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Abstract

Purpose: Deficits in phonological working memory and deficits in phonological processing have both been considered potential explanatory factors in Specific Language Impairment (SLI). Manipulations of the lexicality and phonotactic frequency of nonwords enable contrasting predictions to be derived from these hypotheses.

Method: 18 typically developing (TD) children and 18 children with SLI completed an assessment battery that included tests of language ability, non-verbal intelligence, and two nonword repetition tests that varied in lexicality and frequency.

Results: Repetition accuracy showed that children with SLI were unimpaired for short and simple high lexicality nonwords, whereas clear impairments were shown for all low lexicality nonwords. For low lexicality nonwords, greater repetition accuracy was seen for nonwords constructed from high over low frequency phoneme sequences. Children with SLI made the same proportion of errors that substituted a nonsense syllable for a lexical item as TD children, and this was stable across nonword length.

Conclusions: The data show support for a phonological processing deficit in children with SLI, where long-term lexical and sub-lexical phonological knowledge mediate the interpretation of nonwords. However, the data also suggest that while phonological processing may provide a key explanation of SLI, a full account is likely to be multi-faceted.

Keywords: specific language impairment, nonword repetition, phonological working memory, phonological processing, lexicality.

Introduction

Specific Language Impairment (SLI) is generally defined in terms of impaired language ability in the absence of any impairment to non-verbal abilities (e.g. Conti-Ramsden & Durkin, 2007; Leonard, 2000). Children with SLI display deficits such as being late in acquiring their first words, having smaller vocabularies in general, and showing problems with some or all of the grammatical components of language.

One task that is used extensively to distinguish between children with SLI and their peers is nonword repetition. Administering this task is relatively straightforward: the child repeats aloud nonsense words that are spoken to them. By varying the construction of nonwords, it has been found that, relative to their peers, children with SLI have difficulty producing long nonwords (e.g., Archibald & Gathercole, 2006; Marton & Schartz, 2003; Montgomery, 1995) and nonwords that contain consonant clusters (Archibald & Gathercole, 2006; Briscoe, Bishop & Norbury, 2001; Marshall & van der Lely, 2009).

The relative difficulty that children with SLI have in producing nonwords has been explained as an impairment to phonological working memory (e.g., Ellis Weismer, Tomblin, Zhang, Buckwalter, Chynoweth & Jones, 2000; Gathercole & Baddeley, 1990; Montgomery, 1995), a temporary store for auditory stimuli. Over time, information in phonological working memory decays (e.g., Baddeley, 1986; Roodenrys, Hulme, Lethbridge, Hinton & Nimmo, 2002), causing the representation of the stimuli to become degraded. Since the quality of representation of a nonword declines with nonword length (because long nonwords are more prone to decay), impairments to phonological working memory have the greatest effect on the longest stimuli (Gathercole, 2006).

An alternative account is that children with SLI have a phonological processing deficit (e.g., Bishop, 1997; Bowey, 2006; Chiat, 2001, 2006). The processing of phonological information occurs in many areas of language, and is hence a crucial ability for the accurate repetition of nonwords (e.g., Bowey, 1996, 2001). If children with SLI have difficulty processing phonological information – be it at the encoding, storage, or retrieval stage of the repetition process – then their representations of any spoken nonword will be low in quality. Difficulties in phonological processing will therefore manifest via impaired nonword repetition performance compared to typically developing (TD) children. Repetition deficits will increase with nonword length since processing difficulties increase with the phonemic length of the input.

One method for establishing competing predictions between the phonological working memory and phonological processing hypotheses is to manipulate the lexicality of nonwords. There is now a general consensus that lexical phonological knowledge plays an important role in nonword repetition, at least for TD children. First, TD children have higher repetition accuracy for nonwords constructed from sound sequences occurring frequently in the native language over nonwords constructed from low frequency sequences (e.g., Coady & Aslin, 2004; Edwards, Beckman & Munson, 2004; Vitevich, Luce, Charles-Luce & Kemmerer, 1997). Second, when nonwords are rated for "wordlikeness"[1], those rated high in wordlikeness have higher repetition accuracy than nonwords rated low in wordlikeness (e.g., Frisch, Large & Pisoni, 2000; Gathercole, 1995; Munson, Kurtz &

[1] Subjective ratings of nonwords based on how wordlike people perceive them to be.

Windsor, 2005). Third, children's repetition accuracy increases for nonwords that have been constructed to be more lexical – by replacing a nonsense syllable with a lexical item, such as *fath*esis for *bath*esis (Dollaghan, Biber & Campbell, 1995). Fourth, errors in nonword repetition often involve changing a nonsense syllable to a lexical syllable (Edwards & Lahey, 1998; Dollaghan, Biber & Campbell, 1995). Henceforth we use the term *lexicality* to refer to the degree to which a nonword shares overlap with long-term lexical phonological information; *lexicality effect* to describe any influence that long-term lexical phonological information has on nonword repetition performance; and *lexical error* to describe errors where a syllable in a nonword is replaced by a lexical item during repetition.

Given the wealth of literature indicating clear lexicality effects in nonword repetition for TD children, it is surprising that there is very little direct examination of nonword lexicality in children with SLI. Nevertheless, the same effects seen in TD children would also be expected to occur in children with SLI, given that children with SLI show similar effects of wordlikeness (e.g., Briscoe, Bishop & Norbury, 2001) and strong effects of frequency (e.g., Munson, Kurtz & Windsor, 2005).

For the phonological working memory account, lexicality effects are explained via a process of redintegration (e.g., Schweickert, 1993). Redintegration uses long-term lexical phonological knowledge at the point of retrieval to 'fill in' any parts of nonwords that have become degraded in quality (e.g., Gathercole, 1995, 2006; Thorn, Gathercole & Frankish, 2005). Since the quality of representation of a nonword declines with nonword length, as nonword length increases, the probability of using redintegration also increases. Note that while redintegration may correctly repair a degraded nonword, it can also incorrectly repair the nonword – for example, by replacing a nonsense syllable with a lexical item (i.e., producing a lexical error). The proportion of repetition errors that can be classified as lexical errors should therefore increase with nonword length.

For the phonological processing account, there is evidence relating to adult processing of ambiguous phonological information that can be used to derive predictions about how children with SLI will attempt to resolve processing difficulties. For example, when there is insufficient acoustic information to identify a phoneme, the surrounding phonological context will be used (Norris, McQueen & Cutler, 2003). A sound may therefore be identified as /b/ when followed by /ɔːl/ (ball) and /g/ when followed by /ɜːl/ (girl). This indicates that children with SLI should be less impaired on their repetition of nonwords that are high in lexicality as opposed to nonwords that are low in lexicality, since the former share more characteristics with lexical phonological knowledge. Since any method used to resolve phonological processing difficulties applies across all syllables in the nonword, the proportion of lexical errors should remain stable across nonword length.

One further method by which competing predictions can be established between the phonological working memory and phonological processing accounts is manipulation of the frequency of constituent sounds in low lexicality nonwords. Since redintegration operates on lexical phonological knowledge (e.g., Thorn, Gathercole & Frankish, 2002; Gathercole, 2006), when nonwords are constructed to have minimal lexical influences, their repetition performance should be similar even if the nonwords vary in the frequency of their constituent sounds. The phonological processing account, on the other hand, suggests that long-term sub-lexical knowledge also influences the perception of ambiguous phonetic information. Pitt and McQueen (1998) manipulated the transitional probabilities of vowel-consonant biphones, finding that ambiguous consonants were more likely to be perceived as the consonant that most often followed the vowel in English. This indicates that even for nonwords that are low in lexicality, there should be greater repetition accuracy for high frequency nonwords than low frequency ones.

By examining accuracy and lexical errors for nonwords varying in lexicality and frequency, we can test contrasting predictions made by the phonological working memory and phonological processing accounts of repetition difficulties seen in children with SLI. The phonological working memory account predicts greater repetition accuracy for high lexicality nonwords over low lexicality nonwords for long but not short nonwords. This is because short nonwords are unlikely to become sufficiently degraded in quality to require redintegration on retrieval from memory. Similarly, since the probability of using redintegration increases as nonword length increases, then the proportion of lexical errors[2] should increase as nonword length increases. Finally, there should be little difference in repetition accuracy between low lexicality nonwords that differ in the frequency of their constituent sounds, since redintegration uses long-term lexical phonological knowledge.

For phonological processing, any difficulties in the nonword repetition process are more likely to be successfully resolved for high lexicality nonwords than low lexicality nonwords, since high lexicality nonwords are more similar to existing lexical items. Repetition accuracy for high lexicality nonwords should therefore be superior to low lexicality nonwords at all lengths of nonword. The proportion of lexical errors should remain stable across all nonword lengths, because any method

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[2] Since the raw number of lexical errors may vary with nonword length, what is of interest is how the *proportion* of errors that are classified as lexical errors changes with nonword length.

that is used to resolve phonological processing difficulties is applied with equal probability to each syllable in a nonword. Finally, since phonological processing difficulties can be alleviated by both lexical and sub-lexical knowledge, low lexicality nonwords should have greater repetition accuracy when they consist of high frequency phoneme sequences rather than low frequency ones.

The study presented here compares TD children to children with SLI on two nonword repetition tests that vary in their lexicality, with the low lexicality nonwords also varying in the frequency of their constituent sounds. We examine both repetition accuracy and lexical errors to see if (a) the lexicality of nonwords differentially affects TD children and children with SLI; and (b) to see which of the phonological working memory deficit and phonological processing deficit accounts of SLI best fits the data.

As far as we are aware, only one study has varied the lexicality of nonwords when examining repetition accuracy in children with SLI. Archibald and Gathercole (2006) compare performance on nonwords high in lexicality (the CNRep, Gathercole, Willis, Baddeley & Emslie, 1994) with nonwords low in lexicality (the NRT, Dollaghan & Campbell, 1998). In comparison to TD children, children with SLI show repetition deficits for both types of nonword. However, deficits are more pronounced for high lexicality nonwords than low lexicality nonwords. This finding does not fit a phonological working memory account of the SLI deficit, since nonwords that are high in lexicality should be helped by existing lexical knowledge (e.g., via redintegration). One explanation put forward by the authors is the possibility that children with SLI have difficulty with lexical mediation processes in addition to a phonological working memory deficit. This view is consistent with the above findings because any difficulty in mediating between lexical knowledge and phonological working memory would be expected to hinder high lexicality nonwords more than low lexicality nonwords.

The research presented here adds to the Archibald and Gathercole (2006) study in three important ways. First, we directly compare performance on nonwords that vary in their lexicality but still respect the stress patterns of the English language. No detailed comparisons across lexicality are made in the Archibald and Gathercole study, perhaps because the NRT differs from the CNRep in terms of stress patterns as well as lexicality. In the NRT, nonwords have primary stress on one syllable and secondary stress on all others, a pattern which does not conform to the majority of multi-syllabic English words as these have at least one unstressed syllable. On the other hand, the CNRep nonwords are consistent with the majority of multi-syllabic English words, where one syllable carries primary stress and (in most cases) one or more of the remaining syllables are unstressed. Thus, we have constructed a new set of low lexicality nonwords that have stress patterns consistent with English phonology. The nonwords vary in their phonotactic frequency such that one set contains high frequency phonotactic sequences whilst the other contains low frequency phonotactic sequences, since the phonological working memory and phonological processing accounts make different predictions regarding the frequency characteristics of low lexicality nonwords. Second, we use a narrower range of younger children – the Archibald and Gathercole study uses children with SLI between the ages of 7 and 12 years, whereas the current study uses only 5 and 6 year olds. The vast majority of studies involving children with SLI use children of 7 years and above, so this study also provides further repetition information for younger SLI cohorts. Third, we include an analysis of lexical errors. Analyzing errors is informative about the underlying mechanisms involved in nonword repetition (e.g., Edwards & Lahey, 1998). As we showed above, analyzing lexical errors in particular is a key way to pit the phonological working memory and phonological processing accounts of the SLI deficit against each other.

Although in this paper we explicitly test two accounts of the repetition deficits seen in children with SLI, it should be borne in mind that any explanation of repetition deficits in SLI is likely to be multi-faceted (as suggested above by Archibald & Gathercole, 2006). For example, Gathercole (2006) recognizes contributions from sources other than phonological working memory, such as the quality of phonological representations that are stored in memory. Chiat (2001, 2006) lists several areas of phonological processing that may be affected in children with SLI, while acknowledging that other areas, such as memory capacity, may also be affected. In this paper we establish which of phonological working memory or phonological processing is providing the primary contribution to repetition impairments in children with SLI.

The remainder of the paper is as follows. First, we present the details of the nonword study together with information on the nonword sets. Second, we analyze both repetition accuracy and lexical errors across TD children and children with SLI. Third, we draw conclusions based on the results presented.

Nonword Repetition Study

Participants

Eighteen children with SLI (5;7-6;7, M=6;1; 14 male, 4 female) were recruited from a larger group of children identified as having a possible language impairment by speech and language therapists, educational psychologists, and special educational needs co-ordinators within the Nottingham and South Yorkshire areas of the UK. Three of the children had either undergone or were currently enrolled in speech and language therapy. All children met the criteria for SLI, scoring at least 1 standard deviation below the mean on at least two of four language tests included in the Clinical Evaluation of Language Fundamentals-Preschool 2 UK (CELF-Preschool 2, Wiig, Secord & Semel, 2006)[3] and scoring 85 or above on the combined score for the core tests of performance (i.e., non-verbal) IQ in the Wechsler Preschool and Primary Scale of Intelligence 3 UK (WPPSI-3 UK, Wechsler, 2002). The CELF-Preschool 2 UK language tests comprised the three core tests (sentence structure, word structure, and expressive vocabulary) plus recalling sentences. The WPPSI-3 UK performance IQ tests consisted of block design, matrix reasoning, and picture concepts. The children also completed a test of receptive vocabulary: the British Picture Vocabulary Scale-2 (BPVS-2, Dunn, Dunn, Whetton, & Burley, 1997), and the diagnostic screening test of the Diagnostic Evaluation of Articulation and Phonology (DEAP, Dodd, Hua, Crosbie, Holm & Ozanne, 2002). The screening test is a test of articulation that involves picture naming, where the names of the items depicted cover the majority of consonants, some clusters and a range of vowels. Only 4 children had difficulty in correctly speaking aloud the test items on the DEAP – with all 4 children replacing /θ/ with /f/.

Eighteen TD children (5;7-6;6; M=6;0; 9 male, 9 female) were matched to the children with SLI first and foremost by age (within 2 months), then by school (same school where possible), and then by gender. All TD children matched the children

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[3]12 of the 18 children were over 1.33 SD below the mean (below the 10th centile) on two or more of the four sub-tests.

with SLI for age, 72% were at the same school and 72% were of the same gender. All children scored within normal ranges on all the language and IQ tests. 17 of the 18 children correctly named all test items on the DEAP, with one child replacing /θ/ with /f/. Further details of the cohorts can be found in Table 1.

INSERT TABLE 1 HERE

Materials

High lexicality nonwords. The CNRep (Gathercole, Willis, Baddeley & Emslie, 1994) has been shown to distinguish between TD children and children with SLI in a variety of studies (e.g., Archibald & Gathercole, 2006; Briscoe, Bishop & Norbury, 2001; Conti-Ramsden, 2003). It is for this reason that the CNRep is chosen as one of the nonword tests to administer to the children. The test consists of 40 nonwords, 20 single consonant (e.g., /ˈpenəl/) and 20 clustered consonant (e.g., /ˈglɪstəʊ/). For each nonword type, there are 5 nonwords of 2, 3, 4, and 5 syllables. The test is known to contain many nonwords that receive support from existing lexical and morphological knowledge (e.g., Archibald & Gathercole, 2006; Thal, Miller, Carlson & Vega, 2005). For example, several of the nonwords contain lexical items (e.g., /ˈθɪkəriː/, /ˌstɒpəˈgrætɪk/) and several contain morphological markers (e.g., /ˈslædɪŋ/, /ˈdɒpəˌleɪt/). Note that these nonwords have been split into two sets in the past (e.g., Briscoe, Bishop & Norbury, 2001; Gathercole, 1995): wordlike and non-wordlike. However, even some of the nonwords considered non-wordlike contain lexical items and morphological markers (e.g., /ˈbænəu/, /pəˈnerɪˌfʊl/,

/kənˈtræmpəˌnɪst/) (see also Estes, Evans & Else-Quest, 2007). All the nonwords in the CNRep are therefore considered *high in lexicality*.

We omitted 5-syllable nonwords because we found that 5-6 year old children had difficulty repeating nonwords of this length, leaving 30 nonwords in total. To ensure the child's attention was maintained, the nonwords were split into two blocks of 15. Nonwords were presented in the same random order as provided on the CNRep tape (Gathercole & Baddeley, 1996), but nonwords were converted to MP3 format for ease of administration. The presentation order of the two 15-nonword files was counterbalanced.

Low lexicality nonwords. Two sets of single consonant nonwords were developed: 18 low frequency and 18 high frequency, each comprising 6 nonwords of 2, 3, and 4 syllables. All of the new nonwords are single consonant nonwords because children with SLI have difficulty in producing consonant clusters (e.g., Archibald & Gathercole, 2006; Briscoe, Bishop & Norbury, 2001; Marshall & van der Lely, 2009). Children with SLI are therefore expected to have difficulty repeating nonwords containing consonant clusters, irrespective of their lexicality or frequency.

The frequency of the nonwords was calculated based on biphone frequencies using a similar method to Luce and colleagues (e.g., Jusczyk, Luce & Charles-Luce, 1994; Vitevich et al., 1997; Vitevich & Luce, 1998), but using the Children's Printed Word Database (CPWD, a database of word frequencies based on 5-9 year old children available at *http://www.essex.ac.uk/psychology/cpwd/*) instead of on-line dictionaries to ensure frequencies based on children's language use. High frequency nonwords had an average biphone frequency of 4,538 (range 1,225-13,148); low frequency nonwords had an average biphone frequency of 1,067 (range 3-2,843). No syllables contained any morphological markers or mono-syllabic words that were in the CPWD.

All nonwords conformed to the phonotactics of (Standard British) English. Differences in the spoken duration and vocalic complexities of low and high frequency nonwords were kept to a minimum by ensuring that all nonwords comprised only one long vowel, to be found in the primary stressed position. All nonwords had exactly one (simple) coda consonant, to be found in the last syllable, whilst all other syllables had a simple CV structure.

To ensure that any potential difficulty in producing a nonword of a particular length would result from the added syllable(s) rather than from any extra phonemic complexity, nonwords at each length comprised the shorter nonword plus an extra syllable. For example, /ˈfiːsəd/, /ˈfiːsəˌdɪv/, and /dəˈfiːsəˌdɪv/. Stress patterns were consistent at each length – strong-weak, strong-weak-strong, and weak-strong-weak-strong for 2, 3, and 4 syllables respectively.

The 36 nonwords were split into three groups of 12, ensuring that each group contained only one nonword from each component set (e.g., /ˈtʃaɪgəf/, /ˈtʃaɪgəˌfɪb/ and /jəˈtʃaɪgəˌfɪb/ were placed in different groups), an equal number of nonwords containing low frequency and high frequency phonotactic sequences, and an equal number of 2, 3, and 4 syllable nonwords. One randomized order for each group of 12 nonwords was recorded onto a Sony ICD-MX20 digital voice dictaphone by a researcher who was native to the Nottingham area. Nonwords were converted to MP3 format using Sony Digital Voice Editor, version 3.1 (available from *http://esupport.sony.com/*) and edited using Audacity (*http://www.audacity.sourceforge.net/*) to produce six files: one for each of the three sets of 12 nonwords and the reverse order of each of the three. For each file, nonwords were succeeded by a 3 s period of silence, as per the CNRep nonwords. Each sound file was preceded by a set of instructions consistent with those of the CNRep and as follows: "*Hello, in a few seconds you will hear a funny made up word. Please say the word aloud yourself as soon as you hear it*".

Given that the high lexicality nonwords had previously been separated into wordlike and non-wordlike sets, we confirmed that the newly created low lexicality nonwords were perceived as non-wordlike in comparison to all of the high lexicality nonwords. Eleven adults were presented with the spoken form of all nonwords and rated them for wordlikeness on a 7-point Likert scale (1=Not wordlike, 7=Wordlike). The low lexicality nonwords were perceived as being significantly less wordlike than the high lexicality nonwords (Low lexicality $M = 2.32$, $SD = .61$; High lexicality $M = 4.61$, $SD = .74$; $t(10) = 10.53$, $p < .001$). Furthermore, if only the non-wordlike set of high lexicality nonwords is considered (see Gathercole, 1995), the low lexicality nonwords were still perceived as significantly less wordlike (Non-wordlike $M = 3.97$, $SD = .65$, $t(10) = 9.52$, $p < .001$).

Design

For both the high lexicality (CNRep) and low lexicality (new nonword) tests, group status (SLI or TD) was an independent variable. Within tests, the independent variables for high lexicality nonwords were nonword type (single or clustered consonant) and nonword length (2, 3, or 4 syllables); for low lexicality nonwords they were frequency (high or low) and nonword length (2, 3, or 4 syllables). In all cases, the dependent variables were the accuracy of the repetition and whether a repetition resulted in a lexical error.

Procedure

The study was ethically approved by the School Ethics Research Committee at Nottingham Trent University. All children were assessed on a one-to-one basis in a quiet room within the school and away from their classroom. Testing normally comprised three separate 15-minute sessions spread across several days or weeks (depending on the school and availability of the children). However, on occasion more testing sessions were required (e.g., if all tests for a session could not be completed within a reasonable timescale). Where possible, we ensured that there was at least a 4-day interval between testing sessions for the low and high frequency nonword sets since these overlapped in syllable content.

The first testing session involved the CELF-Preschool, the second involved the WPPSI-3 and the third involved the BPVS-2 and the DEAP. Administration of the nonword tests was distributed across testing sessions, ensuring that where possible only one block from each set of nonwords was presented in a single session. Nonword stimuli were played from a Sony ICD-MX20 digital voice dictaphone (Memory Stick Digital Recorder) through Creative TravelDock 900 Portable speakers. Responses were recorded onto a Sony ICD-MX20 digital voice dictaphone for later transcription.

Results

Nonword repetitions were transcribed in their phonemic form by the third author. For children who replaced /θ/ with /f/ in the DEAP, either of these phonemes was allowed as a correct repetition of a /θ/ target. A random sample of 15% was transcribed by a researcher who was experienced in transcribing nonwords but who was not working on this project. Phoneme-by-phoneme inter-rater reliability was 90.7% for the high lexicality nonwords and 85.4% for the low lexicality nonwords.

For the accuracy data, phoneme additions were ignored in accordance with previous literature on repetition analyses of children (e.g., Dollaghan & Campbell, 1998; Archibald & Gathercole, 2006). Nil responses (.02% of responses) were coded as errors. For the error data, a lexical error was recorded if one or more syllables in a nonword were changed to a syllable(s) that occurred as a lexical item(s) in the CPWD. For all analyses, inaudible responses (.01% of responses) were ignored.

We first consider the repetition accuracy results of the high lexicality and low lexicality nonwords in turn, to illustrate any differences between the TD children and the children with SLI for each nonword set. We then compare the nonword sets to test the repetition accuracy and lexical error predictions that were derived from the phonological working memory and phonological processing accounts of the SLI deficit.

Accuracy

High lexicality nonwords. Figure 1 shows the accuracy data for the high lexicality nonwords for both the children with SLI and the TD children, and Table 2 shows the data expressed numerically. A 2 (group status: SLI or TD) x 2 (nonword type: single or clustered) x 3 (nonword length: 2, 3, or 4 syllables) mixed design ANOVA was performed on the data, with group status as the only between subjects variable. Consistent with all of the research involving this nonword set (e.g., Archibald & Gathercole, 2006; Briscoe, Bishop & Norbury, 2001; Gathercole & Baddeley, 1990), TD children repeated nonwords more accurately than children with SLI ($F(1,34) = 21.93$, $p < .001$, $\eta_p^2 = .39$), single consonant nonwords were repeated more accurately than clustered consonant nonwords ($F(1,34) = 57.93$, $p < .001$, $\eta_p^2 = .63$), and repetition accuracy decreased as nonword length increased ($F(2,68) = 81.09$, $p < .001$, $\eta_p^2 = .71$).

There was also an interaction between group status and nonword type ($F(1,34) = 4.96$, $p = .033$, $\eta_p^2 = .13$). As Figure 1 shows, children with SLI have a much larger deficit for clustered consonant nonwords than single consonant nonwords, while this is less so for TD children (single consonant nonwords: 59% accuracy for TD children; 46% for children with SLI; clustered consonant nonwords: 45% accuracy for TD children; 21% for children with SLI). This is consistent with previous research showing that children with SLI have difficulty in producing consonant clusters (e.g., Gallon, Harris & van der Lely, 2007; Marshall & van der Lely, 2009). None of the other pairwise interactions were significant ($p = .181$ or greater).

There was also a three-way interaction ($F(2,68) = 9.18$, $p < .001$, $\eta_p^2 = .21$). We further analyzed this interaction by conducting post hoc *t*-test comparisons between the TD children and the children with SLI for each nonword type and nonword length (with p set to .008 to cater for familywise error rates). Children with SLI had significantly lower repetition accuracy on all but 2 and 3 syllable single consonant nonwords. This finding mirrors that of Briscoe, Bishop and Norbury (2001) and shows that children with SLI have much clearer repetition deficits for long and complex nonwords.

INSERT FIGURE 1 HERE

INSERT TABLE 2 HERE

Low lexicality nonwords. Figure 2 shows the accuracy data for low lexicality nonwords for both the children with SLI and the TD children. Since 4 syllable repetition performance is at floor level for children with SLI, a 2 (group status: SLI or TD) x 2 (frequency: high or low) x 2 (nonword length: 2 or 3 syllables) mixed design ANOVA was performed on the data. As with high lexicality nonwords, repetition accuracy decreased as nonword length increased ($F(1,34) = 34.79$, $p < .001$, $\eta_p^2 = .51$) and TD children repeated nonwords more accurately than children with SLI ($F(1,34) = 23.02$, $p < .001$, $\eta_p^2 = .40$). There was also higher repetition accuracy for nonwords containing high frequency phoneme sequences over nonwords containing low frequency ones ($F(1,34) = 12.15$, $p = .001$, $\eta_p^2 = .26$).

There were no pairwise interactions (all *p*s = .100 or greater) – an important finding because this indicates that children with SLI are performing below TD children across the board rather than matching the children for some of the shorter nonwords, as in the high lexicality nonword data. However, the three-way interaction was very close to significance ($F(1,34) = 4.11$, $p = .051$, $\eta_p^2 = .11$). As with the high lexicality nonwords, we analyzed this interaction further by conducting post hoc *t*-test comparisons (with *p* set to .013 to cater for familywise error rates). Since children with SLI show a deficit on all types of nonword, we compared performance between nonwords containing high frequency phoneme sequences and nonwords containing low frequency ones, for both groups of children and for both lengths of nonword. For TD children, there was significantly greater repetition accuracy for nonwords containing high frequency phoneme sequences than nonwords containing low frequency phoneme sequences for 3 syllable but not 2 syllable nonwords. Children with SLI, on the other hand, show significantly greater repetition accuracy for nonwords containing high frequency phoneme sequences than nonwords containing low frequency phoneme sequences for 2 syllable but not 3 syllable nonwords. The impact of frequency on repetition performance appears to be linked to the length of the stimuli. For TD children, repeating 2 syllable nonwords is relatively easy and hence no effect of frequency is seen; however, the increase in task difficulty from 2 to 3 syllable nonwords is sufficient to allow frequency effects to emerge. For children with SLI, task difficulty is sufficiently high for 2 syllable nonwords that a frequency effect is seen at this length. This view is supported by the data at higher nonword lengths, where further increases in task difficulty lead to a complete breakdown in performance. For children with SLI, performance starts to hit floor at 3 syllables (where the highest score in any condition is 22%), and for TD children, performance starts to hit floor at 4 syllables (where the highest score in any condition is 23%).

The separate analyses for each of the two nonword sets show that children with SLI match the performance of TD children for some of the simpler and shorter high lexicality nonwords, whereas children with SLI show impaired performance on all of the low lexicality nonwords – regardless of length and frequency. This is an issue we turn to in the next section, where accuracy and lexical errors are examined across the nonword sets in order to test competing hypotheses regarding the SLI deficit.

INSERT FIGURE 2 HERE

Comparisons Across Lexicality

In order to match high and low lexicality nonwords as closely as possible (so that any effects seen are due to lexicality rather than other factors), we compare single consonant high lexicality nonwords to high frequency low lexicality nonwords. All of the low lexicality nonwords are constructed to be single consonant, providing a close match for syllabic structure. High rather than low frequency low lexicality nonwords are the closest match to the single consonant high lexicality nonwords for frequency.

Analyses are based on 2 and 3 syllable nonwords, because performance for 4 syllable high frequency low lexicality nonwords is at floor. Comparing 2 and 3 syllable nonwords still constitutes a good test of the predictions of the phonological working memory account. Previous studies have used the finding that long nonwords (3 syllables or more) show a larger deficit in repetition performance than short nonwords (2 syllables or less) as support for an impairment to phonological working memory – when using older children than those used in the study presented here, and for both low lexicality nonwords (e.g., Ellis Weismer et al., 2000) and high lexicality nonwords (e.g., Archibald & Gathercole, 2006).

Accuracy. A 2 (group status: TD or SLI) x 2 (lexicality: high or low) x 2 (nonword length: 2 or 3 syllables) mixed design ANOVA was performed on the data. We focused on effects involving lexicality, since effects involving the other variables have already been considered. There was a significant effect of lexicality ($F(1,34) = 18.67$, $p < .001$, $\eta_p^2 = .35$) indicating that high lexicality nonwords were repeated more accurately than low lexicality nonwords. Although there was no three-way interaction ($F(1,34) = .05$, $p = .830$, $\eta_p^2 = .01$), there was an interaction between lexicality and group status ($F(1,34) = 16.73$, $p < .001$, $\eta_p^2 = .33$). For TD children, repetition accuracy was 65% for high lexicality nonwords versus 64% for low lexicality nonwords; for children with SLI, repetition was 60% and 33% respectively. While TD children's performance was stable across the high and low lexicality nonwords, this was in stark contrast to the children with SLI: for children with SLI, repetition performance is similar to TD children for high lexicality nonwords but is significantly poorer for low lexicality nonwords. However, it should be noted that lexicality did have an effect in TD children for 4 syllable nonwords, where high lexicality nonwords had a greater repetition accuracy than low lexicality nonwords ($t(17) = 4.00$, $p = .001$).

There was also an interaction between nonword test and nonword length ($F(1,34) = 4.68$, $p = .038$, $\eta_p^2 = .12$). The pattern of means indicates that the decline in performance from 3 syllable high lexicality nonwords to 3 syllable low lexicality nonwords was greater than that for 2 syllable nonwords. That is, 3 syllable nonwords were more affected by lexicality than 2 syllable nonwords.

Figure 3 shows individual repetition accuracy for each of the two nonword tests, for both the TD children and the children with SLI. The accuracy data in the figure emphatically support the statistics above at the level of individual children. For TD children, 6 show a higher repetition accuracy (larger than 5% differential) for high lexicality nonwords over low lexicality ones; 8 show little difference; and 4 show a higher repetition accuracy for low lexicality nonwords over high lexicality ones.

However, the children with SLI show a different pattern: 14 show a higher repetition accuracy for high lexicality nonwords over low lexicality ones; 3 show little difference; and 1 shows a higher repetition accuracy for low lexicality nonwords over high lexicality ones.

INSERT FIGURE 3 HERE

Lexical errors. Error analyses are based on items rather than participants because of variation across participants in the number of errors made. Figure 4 shows the percentage of repetition errors that involve a lexical error[4], across nonword types and lengths, for the TD children and the children with SLI. A lexical error is defined as an error in nonword repetition that involves changing a nonsense syllable(s) to a lexical syllable(s). In order to qualify as being lexical, syllables must occur as words in the CPWD. That is, we only accept as a lexical error those responses that we expect to be in the child's vocabulary.

A 2 (group status: TD or SLI) x 2 (nonword type: high lexicality or low lexicality) x 2 (nonword length: 2 or 3 syllables) mixed design ANOVA was carried out on the data. Importantly, there was no effect or interaction involving group status (p = .406 or greater), showing that TD children and children with SLI were no different in terms of the proportion of their errors that contained a lexical error. There was also no effect of nonword length ($F(1,18) = .57$, $p = .460$, $\eta_p^2 = .15$), showing that

[4] Erroneous repetitions involving a lexical error / (Erroneous repetitions involving a lexical error + Erroneous repetitions not involving a lexical error).

the proportion of lexical error remained stable across length. There was a main effect of nonword type (F(1,18) = 4.79, p = .042, η_p^2 = .21). As Figure 4 shows, there were a higher proportion of lexical errors for high lexicality nonwords than those of low lexicality.

However, there was an interaction between nonword type and nonword length (F(1,18) = 9.72, p = .002, η_p^2 = .42). This is particularly revealing, since it reflects the fact that 2 syllable high lexicality nonwords result in more lexical errors than 2 syllable low lexicality nonwords, whereas the error rates for 3 syllable nonwords are comparable. Given the exceptionally high rates of lexical error for 2 syllable high lexicality nonwords, we examined the number of lexical neighbors for each syllable in a nonword (where a neighbor was defined as a syllable in a nonword that differed from a lexical item in the CPWD by the addition, deletion, or substitution of one phoneme). Syllables in high lexicality 2 syllable nonwords had an average of 15.3 neighbors, compared with 10.6 for 3 syllable high lexicality nonwords, and 8.9 and 7.6 for 2 syllable and 3 syllable low lexicality nonwords respectively. It is neighborhood size rather than item length or lexicality that seems to govern the extent to which children make lexical errors.

Figure 5 shows the percentage of errors that were classified as lexical errors for each child, for both the high lexicality and low lexicality nonwords. For both TD children and children with SLI, 11 children show a greater number of lexical errors for high lexicality nonwords over low lexicality nonwords, 2 show little difference, and 5 show a greater number of lexical errors for low lexicality nonwords over high lexicality nonwords. Both groups of children therefore show a greater propensity to make lexical errors in high lexicality nonwords than low lexicality nonwords. As the above analysis showed, this was primarily caused by the 2 syllable high lexicality nonwords.

INSERT FIGURE 4 HERE

INSERT FIGURE 5 HERE

Discussion

We compared TD children to children with SLI on two tests of nonword repetition varying in their lexicality. For the simplest of high lexicality nonwords, there were no differences in repetition accuracy between TD children and children with SLI. Once nonwords were stripped of lexical influences, however, children with SLI showed a deficit on all nonwords compared to TD children. An analysis of the proportion of errors that were lexical in nature showed that TD children and children with SLI rely on their lexical knowledge to the same extent – irrespective of the type or length of the nonword. For nonwords that were low in lexicality, there was greater repetition accuracy for nonwords containing high frequency phoneme sequences than nonwords containing low frequency phoneme sequences.

One potential explanation we considered for the relative difficulty in producing nonwords for children with SLI was an impairment in phonological working memory. For repetition accuracy, a deficit in phonological working memory should have no effect on performance for short nonwords differing by lexicality since these nonwords do not become degraded in quality. Long nonwords on the other hand will undergo redintegration – and thus long high lexicality nonwords should have superior repetition accuracy than long low lexicality nonwords by virtue of their increased overlap with long-term lexical phonological knowledge. When considering only low lexicality nonwords, since redintegration operates on lexical phonological knowledge, there should be no difference between low lexicality nonwords that contain high frequency phoneme sequences as opposed to those containing low frequency phoneme sequences. For lexical errors, redintegration is more likely to apply to long nonwords than short nonwords because long nonwords are more likely to be subjected to decay – and therefore long nonwords were predicted to show proportionally more lexical errors. In the current study, the accuracy and lexical error predictions of the phonological working memory account find little support.

An alternative account of repetition deficits in children with SLI is a difficulty in processing phonological information. If children with SLI have difficulty processing speech input, then this will affect every nonword irrespective of its length. However, when nonwords are high in lexicality, long-term lexical phonological knowledge can help the child to correctly identify the nonword, while in cases when nonwords are low in lexicality, long-term lexical phonological knowledge cannot be relied upon to the same extent. High lexicality nonwords were therefore expected to show greater repetition accuracy than low lexicality nonwords. Since sub-lexical phonological knowledge is also used to disambiguate spoken input, when nonwords are low in lexicality there should still be an effect of frequency. Low lexicality nonwords containing high frequency phonemes sequences were therefore expected to show greater repetition accuracy than nonwords containing low frequency phoneme sequences. For lexical errors, any method that is used to decipher an impaired phonological representation is applied equally to each syllable in the speech input. Proportionally, therefore, lexical errors were predicted to remain stable across nonword type and nonword length. In the current study, both the accuracy and lexical error results support the predictions from the phonological processing account.

The phonological processing account can also readily explain other effects that are seen in our data. For repetition accuracy, one important finding is the interaction between the lexicality of a nonword and its length – as length increased, the difference in repetition accuracy between low and high lexicality nonwords also increased. Let us assume that, for high lexicality nonwords, any phonological processing difficulties can be resolved using long-term lexical phonological knowledge with a probability of .9 per syllable in a nonword. Low lexicality nonwords have less similarity with long-term lexical phonological knowledge and therefore only have a .7 chance of success per syllable. For high lexicality nonwords, there would be an 81% chance that long-term lexical phonological knowledge is successful in correctly resolving any processing problems for 2 syllable nonwords ($.9 \times .9 = .81$), reducing to 66% for 4 syllable nonwords ($.9 \times .9 \times .9 \times .9 = .66$). For low lexicality nonwords, the chances of success would be 49% and 24% for 2 and 4 syllable nonwords respectively (a 32% difference for 2 syllable nonwords and a 42% difference for 4 syllable nonwords) (see also Bowey, 2006; Brown & Hulme, 1995). The phonological processing account therefore predicts that the difference in repetition accuracy between high lexicality and low lexicality nonwords will increase with nonword length, consistent with our results. Length is clearly a factor in the repetition performance of both TD children and children with SLI, but the effect of length is mediated by the lexicality of the nonwords involved.

We also found that length played a role in the performance of low lexicality nonwords that varied in the frequency of their constituent sounds. TD children showed no significant difference in their repetition accuracy for 2 syllable nonwords that contained high frequency versus low frequency phoneme sequences, yet they did for 3 syllable nonwords. Again, this can be explained via phonological processing. For example, repetition of a syllable containing high frequency phoneme sequences may have a probability of .85 for accurate repetition whereas repetition of a syllable containing low frequency phoneme sequences may have a probability of .75. This would mean that accurate repetition of 2 syllable nonwords comprising high frequency phoneme sequences would be 72% (.85 x .85 = .72) compared to 56% (.75 x .75 = .56) for 2 syllable nonwords containing low frequency phoneme sequences (TD children's accuracy was 71% and 59%). For 3 syllable nonwords, accuracy would be 61% and 42% respectively (TD children's accuracy was 58% and 44%). The repetition performance of children with SLI may be explained in a similar way. The effect of nonword length is therefore also mediated by sub-lexical knowledge – in this case, the frequency of the constituent biphones that comprise nonwords. However, it should be noted that these hypothetical calculations should result in a difference between 4 syllable nonwords containing high frequency sounds and those containing low frequency sounds – whereas the data show that TD children's accuracy scores are 23% and 19% respectively, and those for children with SLI are at floor for both types of nonword. Phonological processing can therefore only provide part of the explanation for the results seen.

The lexical error analysis also sheds light on the key mechanism that is used to determine the extent to which long-term lexical phonological knowledge can help resolve any impaired representation of a speech input. We showed that the proportion of lexical errors was extremely high for 2 syllable high lexicality nonwords whereas all other conditions were comparable. An analysis of neighborhood size showed that the 2 syllable high lexicality nonwords also had larger neighborhoods than all other nonwords. This finding provides strong clues as to how any perceptual issues relating to phonological processing are resolved. For example, there is a high likelihood that any ambiguous phonemes within a syllable can successfully be resolved when the syllable neighborhood is small; when the syllable neighborhood is large, there is a low likelihood that any ambiguities will be resolved successfully. It therefore appears that the mechanisms that attempt to resolve any impaired nonword were accessing lexical neighbors to help in repairing the input. This allows us to further specify what is meant by the similarity between speech input and lexical phonological knowledge – the number of lexical items that can be formed by the addition, deletion or substitution of one phoneme from each syllable of the input.

Our results in general support the hypothesis that a key deficit in SLI is an impairment in phonological processing. We have shown above how changes to the complexity of nonwords – in terms of increases to nonword length and decreases in lexicality and the frequency of constituent phoneme sequences of nonwords – can be explained by a phonological processing account. However, the results also indicate that repetition difficulties seen in children with SLI are multi-faceted. First, there was a much larger deficit in children with SLI for nonwords containing consonant clusters than for nonwords containing singleton consonants only. Although the difficulty with consonant clusters could be explained in part by a phonological processing difficulty (e.g., clustered consonant nonwords such as /ˈslædɪŋ/ are phonemically longer than single consonant nonwords like /ˈpenəl/ even though syllable length is matched), the large deficit shown by children with SLI for these nonwords is suggestive of other factors being involved. One likely explanation is the articulatory complexity of consonant clusters – for example, the age-of-acquisition of clusters is much later than that of vowels and single consonants (e.g., McLeod, van Doorn & Reed, 2001; Smit, Hand, Freilinger, Bernthal & Bird, 1990). Second, there is evidence in the low lexicality nonword data to suggest children with SLI have an impairment to phonological working memory. TD children showed superior repetition accuracy for nonwords that contained high frequency phoneme sequences over low frequency phoneme sequences for 3 but not 2 syllable nonwords, whereas children with SLI showed the reverse. In the latter case, this was explained by the very poor performance in general for 3 syllable nonwords in the children with SLI that was only evident in the TD children for 4 syllable nonwords. It is therefore possible that children with SLI have a deficit in phonological working memory capacity over and above any difficulty in phonological processing. The results suggest that while impaired phonological processing may play a key role in SLI, there are other factors that influence performance. Amongst others, Gathercole (2006) suggests a framework for nonword repetition and word learning whereby multiple factors such as phonological storage and articulatory complexity influence performance; Chiat (2001, 2006) discusses several factors in addition to length that may influence repetition performance, such as prosodic information in speech (suggesting it is the quality of what is stored as well as the quantity that is important); and both Jones, Gobet and Pine (2007, 2008) and Gupta (2006) suggest models of nonword repetition where impairments can be multiply determined. Further research is necessary in order to identify these additional mechanisms.

Finally, although the phonological processing account is consistent with much of the data from the children with SLI, it fails to account for some of the data from the

TD children. One particular result is intriguing: lexicality effects are more pronounced for children with SLI than they are for TD children, despite children with SLI having smaller vocabularies (see Table 1). The repetition accuracy of TD children should at the very least be greater for high lexicality nonwords than low lexicality nonwords, since the former benefit from existing lexical phonological knowledge. In fact, when comparing high lexicality and low lexicality nonwords at each syllable length, TD children only showed superior repetition accuracy for high lexicality 4 syllable nonwords. The most obvious explanation is that TD children are performing at ceiling for 2 and 3 syllable high lexicality nonwords. We have administered the CNRep to adult participants, finding that performance does not reach 100% on any of the nonword types. Furthermore, Briscoe, Bishop and Norbury (2001) administered the CNRep to a significantly older set of TD children (*M* = 8;6) than those used in the current study, who averaged approximately 85% for simple 2 and 3 syllable nonwords. An alternative explanation is that phonological working memory may play a role in children's repetition performance. Since TD children only show an effect of lexicality for 4 syllable nonwords, it may be the case that 2 and 3 syllable nonwords are not compromised by phonological working memory capacity whereas 4 syllable nonwords are. Further research is necessary in order to establish whether the absence of lexicality effects in TD children is consistent with either of the above explanations or other alternatives.

This study has shown how nonword repetition tests that vary in their lexicality can be used to increase our theoretical understanding of the SLI deficit. On the one hand, the accuracy data revealed how lexical and sub-lexical phonological knowledge influences the repetition performance of children with SLI. On the other hand, the lexical error data revealed how lexical phonological knowledge, in the form of the neighborhood size of nonsense syllables, influences repetition performance for both TD children and children with SLI. Together, the accuracy and error data show how the repetition performance of children with SLI may primarily be characterized by a phonological processing deficit whereby lexical and sub-lexical phonological knowledge mediate the interpretation of nonword stimuli. However, the data also suggest that while phonological processing may provide a key explanation of SLI, a full account is likely to be multi-faceted.

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