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Lexical Representations in Children With SLI: Evidence From a Frequency-Manipulated Gating Task

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Abstract

Purpose—This study investigated lexical representations of children with specific language impairment (SLI) and typically developing, chronological age-matched (CA) peers on a frequency-manipulated gating task. The study tested the hypothesis that children with SLI have holistic phonological representations of words, that is, that children with SLI would exhibit smaller effects of neighborhood density on gating durations than CA peers and that children with SLI would be as efficient as CA peers in accessing high-frequency words but that they would differ from their age-matched peers in accessing low-frequency words.

Method—Thirty-two children (ages 8;5–12;3 [years;months]) participated: 16 children with SLI and 16 typically developing peers matched on age and nonverbal IQ. Children's word guesses after different gating durations were investigated.

Results—Contrary to predictions, no group differences in effects of distributional regularity were found: Children in both groups required equally longer acoustic chunks to access words that were low in frequency and came from dense neighborhoods. However, children with SLI appeared to vacillate between multiple word candidates at significantly later gates when compared with children in the CA group.

Conclusions—Children with SLI did not exhibit evidence for phonologically holistic lexical representations. Instead, they appeared more vulnerable to competing words.

Keywords

SLI; lexical representation; word frequency; neighborhood density

This study investigated lexical access in children with specific language impairment (SLI) and typically developing peers on a frequency-manipulated forward gating task. *Specific language impairment* refers to a developmental condition in which children exhibit difficulty acquiring language in the absence of other neurodevelopmental, frank

neurological, hearing, emotional, or nonverbal intellectual impairments (Leonard, 1998; Tomblin, Records, & Zhang, 1996). Clinically, delayed onset of lexical acquisition is, in most cases, the first indication of SLI, and children with SLI can be differentiated from their typically developing peers on the basis of estimates of vocabulary size, standardized vocabulary tests, and the number of different words produced in spontaneous language samples (Bishop, 1997; Watkins, Kelly, Harbers, & Hollis, 1995).

Lexical processes have been shown to be compromised in SLI in many experimental studies. Children with SLI exhibit slower speeds of lexical processing as compared with their peers. They exhibit slower speed of naming (Lahey & Edwards, 1996; Leonard, Nippold, Kail, & Hale, 1983) and slower reaction times in word recognition experiments (Edwards & Lahey, 1996). Children with SLI also make naming errors, both phonological errors (Lahey & Edwards, 1999) and semantic errors (McGregor & Appel, 2002; McGregor, Newman, Reilly, & Capone, 2002), at higher rates than their peers. Several studies have shown that in novel word learning tasks, children with SLI exhibit poorer performance when compared with their peers (Dollaghan, 1987; Ellis Weismer & Hesketh, 1993, 1996; Oetting, Rice, & Swank, 1995; Rice, Oetting, Marquis, Bode, & Pae, 1994). In the study by Rice and colleagues (1994), children with SLI required up to three times as many exposures to novel words in order to make gains comparable to their age-matched peers. Furthermore, whereas the typically developing children maintained the novel word representations, the children in the SLI group were more likely to forget the novel words after a few days had passed. Children with SLI have also been found to be more susceptible to external perturbations in novel word learning. Ellis Weismer and Hesketh (1993, 1996) reported that children with SLI were more adversely affected by the fast speaking rate than both the age- and language-matched controls.

Dollaghan (1998) and Montgomery (1999) used an interesting paradigm, the gating task, to study lexical access in children with SLI. In the gating task, the participants hear stimulus words presented in successive gates—that is, fragments of the auditory stimulus (Grosjean, 1980). In the most common form of the auditory gating task, the forward gating task, the gates start from the beginning of the word and become increasingly larger. The participant's task is to guess the word based on this incomplete acoustic signal. Both Dollaghan (1998) and Montgomery (1999) found that children with SLI did not differ from their age-matched peers in the length of acoustic signal they needed to recognize highly familiar lexical items. However, Dollaghan observed that children with SLI required significantly more acoustic-phonetic information (i.e., longer gate durations) to recognize newly taught words as compared with typical peers. Dollaghan argued that this pattern of differences in the amount of acoustic-phonetic information needed by children with SLI to activate lexical representations of familiar and unfamiliar words reflects difficulty representing phonological information of newly learned words.

Effects of Distributional Language Regularity in Lexical Access

Effects of distributional language regularity, such as word frequency, and neighborhood density on lexical access are well documented in typical populations. Familiarity of words has been shown to impact lexical access in typical adults (Luce & Pisoni, 1998) as well as

children (Metsala, 1997a; Walley, Michela, & Wood, 1995). The observation that high-frequency words are processed more efficiently as compared with low-frequency words has been reported in experiments using a variety of methods. Adults are faster at recognizing high-frequency words and slower at recognizing low-frequency words on tasks like perceptual identification of words in noise, auditory lexical decisions, and word repetition (Luce & Pisoni, 1998). The effects of word frequency are also present in gating tasks; adults require less acoustic information to recognize high-frequency words as compared with low-frequency words (Grosjean, 1980; Metsala, 1997a; Walley et al., 1995). These effects are also present in children. In gating tasks, children, like adults, require less acoustic information to recognize high-frequency words as compared with low-frequency words (Metsala, 1997a; Walley et al., 1995).

Dollaghan's (1998) notion of difficulty representing novel phonological information in children with SLI can be further examined by investigating the effects of phonological neighborhoods. *Neighborhood density* refers to the number of similar-sounding words in a language or, in practice, a language corpus. The concept of neighborhood density reflects a view that words are represented in terms of their phonological properties, and word recognition is seen as a process of discriminating among competing representations that share similar phonological properties (Luce & Pisoni, 1998). Words that share similar phonological features are seen as phonological neighbors. Consistent with this type of representational architecture, factors related to neighborhood structure as well as word frequency have been shown to impact word recognition in adults. High neighborhood density has an inhibitory effect on word recognition (Garlock, Walley, & Metsala, 2001; Luce & Pisoni, 1998; Vitevitch & Luce, 1998, 1999). Adults are faster and more accurate at recognizing words that have few similar-sounding neighbors (i.e., come from sparse neighborhoods) and slower and less accurate at recognizing words that have many similar-sounding neighbors (i.e., come from dense neighborhoods). The inhibitory effects of neighborhood density are thought to be due to the activated lexical representations competing with each other during the process of spoken word recognition; the more neighbors, the larger the effects of the competition (Luce & Pisoni, 1998).

Distributional Language Regularity in the Developing Lexicon

The notion of neighborhood density has been applied to studies of typical development in the context of arguments for holistic lexical representations in young children. Treiman and Baron (1981) proposed that young children do not store words in terms of sequences of individual segments but rather as indivisible wholes. These holistic lexical representations persist for an extended period of time, presumably until the acquisition of many similar-sounding words forces children to attend to segmental detail. Even though prelinguistic infants can discriminate between phonemic contrasts (Eimas, Siqueland, Jusczyk, & Vigorito, 1971), they lack access to the segmental details of words. Preschoolers cannot, for example, repeat a word without a particular segment (Rosner & Simon, 1971) or group words based on a single phoneme (Treiman & Zukowski, 1991). Preschoolers also tend to group words together based on overall similarity, whereas adults most often group words based on a single shared phoneme (Treiman & Breaux, 1982). Traditionally, these findings have been interpreted as evidence for lack of metalinguistic phonological awareness in

young children. However, evidence from studies of the structure of children's vocabularies and experimental paradigms, such as the gating task, have led some investigators to believe that the basic unit in children's phonological representations is not a phoneme but a larger unit (Fowler, 1991; Metsala, 1997a). Based on analyses of children's vocabularies, Charles-Luce and Luce (1990, 1995) argued that the phonological neighborhoods of young children are sparsely populated, enabling holistic lexical representations. Over the course of development, representations become more detailed as phonological neighborhoods become more densely populated. Supporting this view, children require significantly more acoustic information to recognize words in gating tasks when compared with adults, perhaps reflecting the developmental process of phonological specification of lexical representations (Elliot, Hammer, & Evan, 1987; Garlock et al., 2001; Walley et al., 1995). Furthermore, the inhibitory effects of high neighborhood density on word recognition are shown to be emergent in children. Although elementary school-aged children have shown inhibitory effects of high neighborhood density in gating and word repetition tasks (Metsala, 1997a, 1997b; Garlock et al., 2001), these effects are smaller when compared with adults (Metsala, 1997a, 1997b). Even younger children (preschoolers) do not show any effects of neighborhood density on gating durations (Garlock et al., 2001). Also consistent with the idea of emerging effects of neighborhood structure, younger children (preschoolers) exhibit the inhibitory effects of neighborhood density only in repeating early acquired words but not in repeating later acquired words (Garlock et al., 2001; Metsala, 1997b). Finally, Storkel (2002) reported that preschool children's performance on a similarity classification task is dependent on neighborhood density, suggesting that in their vocabularies, words in dense neighborhoods are represented with more detail than words in sparse neighborhoods. Therefore, evidence from multiple tasks suggests that the organization of children's lexicons changes developmentally, and at any given point, factors such as the number of neighbors, age of acquisition, and word frequency have an impact on how detailed particular lexical representations are.

Current Study

Given that lexical phonological representations of typically developing children have been shown to become more detailed over the course the development, as evidenced by emergent effects of neighborhood density, and given that it has been suggested that children with SLI may have difficulty establishing robust phonological representations, we set out to investigate the effects of word frequency and neighborhood density on lexical access in children with SLI. We hypothesized that if children with SLI have holistic lexical representations, we should find a smaller effect of neighborhood density in the SLI group as compared with peers on the gating task. Furthermore, we predicted that children with SLI would be as efficient as their age-matched peers in accessing words that are high in frequency but less efficient in accessing words that are low in frequency.

The questions to be addressed were (a) would children with SLI and CA peers demonstrate differences in the length of the acoustic chunks needed to access words differing in word frequency and neighborhood density? and (b) would the advantages of high word frequency and low neighborhood density be greater or the same for the SLI as compared with the CA

group? That is, would group interact with word frequency and/or neighborhood density in identifying the gated words?

Method

Participants

Thirty-two children (ages 8;5–12;3), 16 with SLI and 16 typically developing, chronological age and nonverbal IQ matched peers (CA), participated. The age range was set to be comparable to the age range Metsala (1997a, 1997b) used in her gating experiments. We used a matching criterion of ± 9 months¹ and ± 7 standard nonverbal IQ points. The children were part of larger ongoing investigations at the Child Language and Cognitive Processes Laboratory and were originally recruited from the Madison, Wisconsin, metropolitan area schools.

All children met the following inclusion criteria: (a) Performance Intelligence Quotient above 85 as measured by the Leiter International Performance Scale (LIPS; Roid & Miller, 1997); (b) normal hearing based upon American Speech-Language-Hearing Association guidelines for hearing screening; (c) normal oral and speech motor abilities as observed by a certified (Certificate of Clinical Competency) SLP; and (d) a monolingual, English home environment.

Children were not eligible to participate if they had any of the following conditions based upon parent report: (a) neurodevelopmental disorders besides SLI, (b) emotional or behavioral disturbances, (c) motor deficits or frank neurological signs, or (d) seizure disorders or use of medication to control seizures.

All children completed a series of standardized language testing. Receptive and expressive language skills were assessed using the Clinical Evaluation of Language Fundamentals, Third Edition (CELF-3; Semel, Wiig, & Secord, 1995). Receptive and expressive vocabulary was assessed using the Peabody Picture Vocabulary Test, Third Edition (PPVT-III; Dunn & Dunn, 1997) and the Expressive Vocabulary Test (EVT; Williams, 1997), respectively. The results for the standardized testing are found in Table 1.

The language testing criterion for inclusion in the SLI group was a score of -1.25 *SD* below the mean or lower in one or both of the following: CELF-3 Expressive Language Score and CELF-3 Receptive Language Score. In addition, vocabulary knowledge was assessed using PPVT-III Standard Score or EVT Standard Score. The language testing criteria for inclusion in the CA group was a score above -1.00 *SD* below the mean in all of the following: CELF-3 Expressive Language Score, PPVT-III Receptive Vocabulary Standard Score, and EVT Expressive Vocabulary Standard Score. Typically developing children's overall receptive language abilities were also screened using the Concepts and Directions subtest of the CELF-3 receptive battery. None of the children in the typically developing group received a standard score below -1 *SD* in the Concepts and Directions subtest. Furthermore,

¹We used the relatively lenient matching criterion ± 9 months, as we assumed that the changes in language development in this older age group are not as rapid as in younger age groups. This is reflected, for example, in standardized language tests such as the CELF-3 (Semel et al., 1995) that provide raw-to-standard score conversions in 11-month intervals for the older age groups.

none of the typically developing children had a history of services in speech, language, or learning disabilities.

As can be seen in Table 1, the SLI and CA groups differed significantly on all of the language measures. The groups differed significantly on CELF-3 Expressive Language Scale, $t(30) = 8.97, p < .05$; CELF-3 Concepts and Directions receptive subtest scores, $t(30) = 8.00, p < .01$; PPTV standard scores, $t(30) = 4.65, p < .05$; and EVT standard scores, $t(30) = 5.43, p < .01$. Children in the SLI and CA groups did not differ significantly on nonverbal IQ as measured by LIPS performance IQ, $t(30) = 1.35, p > .05$.

In the SLI group, 11 children were White, 3 were African American, and 2 were biracial. In the CA group, 15 children were White and 1 was African American.

Stimuli

We chose a set of 48 monosyllabic target words based on word frequency, neighborhood density, and initial sounds. We obtained the word frequency counts for the words from the spoken word count of 7-year-olds published by Moe et al. (1982) and the neighborhood density counts from the Washington University in St. Louis Speech and Hearing Laboratory (n.d.) neighborhood density calculator. The frequency counts for the calculator were taken from the Hoosier Mental Lexicon (Nusbaum, Pisoni, & Davis, 1984) based on the Brown corpus (Kucera & Francis, 1967). We created four frequency categories, resulting in 12 words in each category: (a) high word frequency (WF), high neighborhood density (ND); (b) high WF, low ND; (c) low WF, high ND; and (d) low WF, low ND. More information on the choice of words, their frequency counts, and the balancing of the frequency counts are presented in the Appendix.

For the purpose of controlling for the perceptual difficulty of the initial sounds of the words, we equated the words with initial consonants: Each of the four frequency categories included words beginning with the exact same consonants, with one exception. Whereas for the three categories (a) high WF, high ND; (c) low WF, high ND; and (d) low WF, low ND one word began with the sound /n/, for the (b) high WF, low ND category we replaced the word beginning with /n/ with a word beginning with /m/. We resorted to this because of the limited number of words that would fill all the criteria.

A female speaker with an upper-Midwestern accent read the words in a soundproof chamber. We recorded the words directly to a Windows-based waveform program digitizing at 44.1 kHz with 16-bit resolution. Each of the words was recorded multiple times at varying speaking rates, and the duration closest to 660 ms was chosen. We used the Sound Edit program to create the gated stimuli. Stimuli including gates at 120, 180, 240, 300, 360, 420, 480, 540, 600, and 660 ms duration were created. We inserted a signal tone to alert the child at the beginning of each trial and gave 3 s of silence after each trial to allow for a response. For the presentation of the words, we followed a duration-blocked format. We did not present the different gate durations for a particular word temporally adjacent (successive format), but instead, we presented particular gate durations for all words temporally adjacent (duration-blocked format). For example, we presented all 120-ms gates for several words before moving to 180-ms gates. Evidence from typical adults and children indicate that the

most commonly used successive format produces isolation points at later gates than those found in a duration-blocked format (Walley et al., 1995). Investigators have suggested that this is perhaps due to factors such as perseveration and negative feedback from the previous gate durations. We speculated that children with SLI might be more vulnerable to such effects when compared with typically developing children and chose a duration-blocked format, unlike Dollaghan (1998) and Montgomery (1999).

We created four different CDs with 12 gated words on each of the CDs. Each of the four CDs contained 3 randomly chosen gated words from the four frequency categories. We counterbalanced the order of the presentation of the four CDs over the two groups.

Procedure

The standardized testing was completed during three earlier visits to the Child Language and Cognitive Processes Laboratory. To ensure that we had the most current testing information, we confirmed that no longer than 8 months had passed since the standardized testing was conducted.

For the experimental task, we asked the children to play a guessing game in which they would hear pieces of words and try to guess the word after each piece. We encouraged the children to guess even when they were not sure. The following instructions were read to the child: “Now you will play a word guessing game. Your job is to listen to some pieces of words. First, you’ll hear a little beep. Then you’ll hear a piece of a word. Then I want you to guess what the whole word is. Then you’ll hear another beep, another piece of a different word and you’ll make another guess. At first the pieces will be short. Then they’ll get longer. You’ll get ten chances to guess each word. Sometimes you might need to change your guess, when you hear a bigger piece of the word. That’s fine. I just want you to make your very best guess after every piece you hear. Let’s practice.” The children completed four gated practice words. During the practice, all children learned to respond appropriately after the gates.

We presented the stimuli to the children in a soundproof chamber at the 75-dB level with the speaker positioned approximately 2 ft away from the child. We recorded the children’s responses using a Sony minidisc recorder and an external Lavalier microphone and simultaneously handwrote the responses orthographically on an answer sheet.

Completion of each of the four gating CDs took approximately 10 min. In between the four CDs, children were offered short breaks and also completed parts of a categorical perception task (Coady, Evans, Mainela-Arnold, & Kluender, 2007). The whole session lasted approximately 1.5 hr including a longer snack break halfway through the session.

Coding—We transcribed the children’s responses orthographically after each gate. In determining whether the word was correctly identified, we allowed minor articulatory errors, with the criterion being whether the word could be correctly identified by the transcriber. Further, we did not consider addition of morphemes an error; for example, *played* was considered correct for the word *play*. We determined three counts for each child: (a) point of target first sound, or the gate at which the child first produced a word with the correct initial

sound, for example, *bear* as a correct target first sound for the word *big*; (b) point of isolation, or the gate at which the child first correctly identified the target word, whether or not they changed their response at subsequent gate durations; and (c) point of acceptance, or the gate after which the child did not change from a correct response. When determining the point of acceptance, we did not count cases in which the child did not respond at all after a gate towards an altering of a word. Not responding after each gate was rare. All children responded to all of the words. If the child did not correctly repeat the word after the 10th gate (i.e., after the whole word was presented), a value of 10.5 was assigned. Consider the hypothetical example of the child hearing progressively larger acoustic portions of the word *big* by responding (1) “will,” (2) “bear,” (3) “big,” (4) “bit,” (5) “big,” (6) “big,” (7) “big,” (8) “big,” (9) “big,” and (10) “big.” In this case, the point of target first sound is the second gate, in which the child first selected a word starting with the target /b/. The point of isolation is the third gate, in which the child first correctly identified the target word *big*, even with the incorrect response at the next gate duration. The point of acceptance is the fifth gate, after which the child did not deviate from the correct response.

Reliability—We established reliability of the coding by having a second person code 19% of the children’s answers. Point-to-point reliability for the three variables was high: 95% for the point of correct first sound, 97% for the point of isolation, and 97% for the point of acceptance.

Results

Point of Target First Sound

This analysis was aimed at investigating the effects of word frequency and neighborhood density on the children’s perception of the first sounds of the gated words and children’s ability to activate words beginning with the perceived sound in their lexicons. The means and standard deviations for this variable are presented in Table 2. As can be seen, the group differences were minimal.

We performed a Group $\times$ Word Frequency $\times$ Neighborhood Density analysis of variance (ANOVA) with point of target first sound as the dependent variable. The group differences did not reach significance. The main effect of group, $F(1, 30) = 3.33, p > .05, \eta^2 = .10, power = .42$; the Group $\times$ Word Frequency interaction, $F(1, 30) = .00, p > .05, \eta^2 = 0, power = .05$; the Group $\times$ Neighborhood Density interaction, $F(1, 30) = .14, p > .05, \eta^2 = 0, power = .07$; and the Frequency $\times$ Neighborhood density $\times$ Group interaction, $F(1, 30) = 1.38, p > .05, \eta^2 = .04, power = .21$, were all nonsignificant, suggesting that the children in the SLI and CA groups were equally proficient at perceiving the first sounds of the gated words and activating words beginning with the perceived sound in their lexicons.

For the two groups collapsed, the Word frequency $\times$ Neighborhood density interaction reached significance, $F(1, 30) = 4.95, p < .05, \eta^2 = .14, power = .68$. Children produced words with correct initial sounds at significantly earlier gates when the words were of high rather than low frequency and came from a sparse neighborhood, $F(1, 30) = 5.87, p < .05$. No effect of word frequency was observed when the stimuli words were from a dense neighborhood, $F(1, 30) = .56, p > .05$. The main effects of word frequency and

neighborhood density did not reach significance: word frequency, $F(1, 30) = 1.38, p > .05, \eta^2 = .04, power = .20$; neighborhood density, $F(1, 30) = .28, p > .05, \eta^2 = .01, power = .08$.

Point of Isolation

We investigated the point of isolation, that is, the two groups' ability to isolate the target words in their lexicons based on acoustic chunks of the words. The means and standard deviations for this variable are presented in Table 2 and Figure 1. Again, the observed group differences were minimal.

We performed a Group $\times$ Word Frequency $\times$ Neighborhood Density ANOVA with point of isolation as the dependent variable. We did not find group differences in children's ability to activate target words in their lexicons. The main effect of group did not reach significance, $F(1, 30) = 2.57, p > .05, \eta^2 = .08, power = .34$, nor did the interactions with the group: Group $\times$ Word Frequency $\times$ Neighborhood Density, $F(1, 30) = 3.22, p > .05, \eta^2 = .10, power = .41$; Group $\times$ Word Frequency, $F(1, 30) = .75, p > .05, \eta^2 = .02, power = .13$; and Group $\times$ Neighborhood Density, $F(1, 30) = .02, p > .05, \eta^2 = 0, power = .05$. This suggests that children with SLI and CA peers were equally efficient in activating the correct target words for all word frequency–neighborhood density combinations.

We did, however, find effects of distributional regularity for the two groups combined. A significant Word Frequency $\times$ Neighborhood Density interaction was found, $F(1, 30) = 39.50, p < .05, \eta^2 = .57, power = 1.0$. In the case of high-frequency words, words with many neighbors were identified at significantly later gates than words with few neighbors, $F(1, 30) = 33.83, p < .05$. In the case of low-frequency words, words with many neighbors were identified at significantly earlier gates than words with few neighbors, $F(1, 30) = 15.07, p < .05$. A significant main effect of word frequency was also found, $F(1, 30) = 7.07, p < .05, \eta^2 = .19, power = .73$, indicating that for both groups, the high-frequency words were identified at earlier gates than the low-frequency words. The main effect of neighborhood density also reached significance, $F(1, 30) = 10.35, p > .05, \eta^2 = .26, power = .88$, indicating that overall, words from dense neighborhoods were identified at later gate durations than words from sparse neighborhoods.

Point of Acceptance

We then examined the point of acceptance, that is, the impact of word frequency and neighborhood density on the two groups' ability to commit to the once-correctly identified target words in their lexicons. We performed a Group $\times$ Word Frequency $\times$ Neighborhood Density ANOVA with point of acceptance as the dependent variable. Table 2 and Figure 2 present these data. As can be seen in both, we did find group differences for this variable.

A significant main effect of group, $F(1, 30) = 5.32, p < .05, \eta^2 = .15, power = .61$, shows that the SLI group did not settle on the correct response until a later gate duration than the CA group, suggesting that the SLI group appeared to vacillate between multiple word candidates at later gates when compared with the CA group. Although the SLI group appeared to receive slightly more facilitation from high word frequency when compared with the CA group, the Group $\times$ Word Frequency interaction did not reach significance:

Group $\times$ Word Frequency interaction, $F(1, 30) = 3.12, p > .05, \eta^2 = .09, power = .40$. The Group $\times$ Neighborhood Density interaction, $F(1, 30) = .97, p > .05, \eta^2 = .03, power = .16$, and the Group $\times$ Word Frequency $\times$ Neighborhood Density interaction, $F(1, 30) = 2.46, p > .05, \eta^2 = .08, power = .33$, did not reach significance either.

Collapsed across the levels of group, effects of distributional regularity were found. The Word Frequency $\times$ Neighborhood Density interaction was significant, $F(1, 30) = 15.34, p < .05, \eta^2 = .34, power = .97$. For high-frequency words, children narrowed down the correct word candidates from sparse neighborhoods at earlier gates than words from dense neighborhoods, $F(1, 30) = 14.25, p < .05$. For low-frequency words, children narrowed down words from high density neighborhoods at earlier gates than words from low density neighborhoods, $F(1, 30) = 6.37, p < .05$. In addition, a significant main effect of word frequency, $F(1, 30) = 24.49, p < .05, \eta^2 = .45, power = 1.0$, was found, indicating that overall, high-frequency words were narrowed down at earlier gates than low-frequency words. The main effect of neighborhood density did not reach significance, $F(1, 30) = 2.80, p > .05, \eta^2 = .09, power = .37$.

Statistical Power

Because we did not find significant group differences for the point of target first sound, isolation, and acceptance ANOVA analyses (with the exception of main effect of group for the point of acceptance), we considered the possibility that the lack of significant effects was due to insufficient statistical power. Indeed, the only significant group difference, the main effect of group for point of acceptance, had an effect size of $\eta^2 = .15$ and a power of .61. This suggests that with power above .80, the effect size for this significant effect might have been larger and that the experiment might have lacked statistical power to detect smaller effects for the other group differences. Therefore, we conducted the three ANOVA analyses with 3 additional participants added to the both the SLI and CA groups. This resulted in an SLI group of 19 children and CA group of 19 children (ages 8;5–12;3). The 3 added children filled the criteria described in the Participants section, and the groups were matched for chronological age but not for nonverbal IQ. With the 6 additional children added to the two groups, the children in the SLI group had significantly lower LIPS performance IQ scores in comparison to the CA group, $t(36) = 2.67, p < .05$. For the three ANOVA analyses repeated with these larger groups, the pattern of significance of findings was exactly the same as we found for the smaller groups. As was the case for the original ANOVA analyses, the only significant group difference was a significant main effect of group for point of acceptance, $F(1, 36) = 8.56, p < .05, \eta^2 = .19, power = .81$. Importantly, with the power of .81 combined with a relatively small detected effect size of $\eta^2 = .19$, we concluded that our experiment had sufficient power to detect relatively small group differences.

Nontarget Words

Because we found an overall group difference for the point of acceptance, we performed an analysis of the non-target words children activated during the gating task. Children in the SLI group produced significantly more nontarget words per each gated word than children in the CA group (SLI: $M = 4.30, SD = .68$; CA: $M = 3.46, SD = .77$), $F(1, 30) = 10.5, p < .05, \eta^2 = .26$. We then divided the nontarget words the children produced into (a) words sharing

the initial sound with the target word, (b) words sharing a rhyme with the target word, and (c) words with no apparent relationship to the target words. The most common nontarget words the children produced shared an initial sound with the target word. The children with SLI produced a slightly smaller percentage of nontarget words that shared initial sounds (SLI: $M = 94\%$, $SD = 6.35$; CA: $M = 98\%$, $SD = 5.91$), but this difference did not reach significance, $F(1, 30) = 3.71$, $p > .05$, $\eta^2 = .11$. Children in both groups produced few nontarget words that shared a rhyme with the target word (SLI: $M = 1.91\%$, $SD = .27$; CA: $M = 0.80\%$, $SD = .20$) and the difference between the two groups was not significant, $F(1, 30) = 1.94$, $p > .05$, $\eta^2 = .06$. Although nontarget words that bore no apparent relationship to the target words were not common in either group, children with SLI produced a larger percentage of these types of nontarget words (SLI: $M = 5.92\%$, $SD = 2.71$; CA: $M = 3.81\%$, $SD = 3.16$), $F(1, 30) = 4.11$, $p < .05$, $\eta^2 = .12$.

Discussion

Our main prediction was that lexical representations in children with SLI differ from those found in typical CA peers; that is, the two groups are differently affected by word frequency and neighborhood density in perceiving words in the context of the gating task. More specifically, we predicted that if children with SLI have holistic phonological representations of words, we should see smaller effect of neighborhood density on gating durations in the SLI group as compared with CA peers. Furthermore, we predicted that children with SLI would be as efficient as their age-matched peers in accessing words that are high in frequency but that they would differ from their age-matched peers in accessing words that are low in frequency. We analyzed three measures: (a) the point of target first sound—the gate at which the child expressed a word beginning with the target sound, (b) the point of isolation—the gate at which the child first expressed the target word, and (c) the point of acceptance—the gate after which the child did not alter the once-correctly identified word. Contrary to what we predicted, we found no interactions between group and distributional language regularity (i.e., word frequency and/or neighborhood density) on any of the measures. This suggests that at least for the words and the distributional regularity levels and/or the age range we examined, children with SLI did not exhibit evidence for holistic lexical representations. Even though we found that the two groups of children were not differentially affected by word frequency and neighborhood density, we did find effects of both for both groups: In the case of high-frequency words, words with many neighbors were identified at significantly later gates than words with few neighbors. In the case of low-frequency words, words with many neighbors were identified at significantly earlier gates than words with few neighbors. For both groups, high-frequency words were identified at earlier gates than the low-frequency words, and words from dense neighborhoods were identified at later gate durations than words from sparse neighborhoods. These results are consistent with what have been reported for both typically developing children and adults (Grosjean, 1980; Metsala, 1997a; Walley et al., 1995) and give further evidence for the notion that children with SLI (at least in this age range) may not have holistic representations of lexical items.

In addition to finding no group differences for effects of distributional regularity, we found no overall group differences for point of correct first sound and point of isolation. This

suggests that the two groups were close to equally proficient at perceiving the initial sounds, at retrieving words beginning with the sound from their lexicons, and also at activating the correct target words in their lexicons. This finding is consistent with the gating study conducted by Montgomery (1999) but somewhat different from the gating study conducted by Dollaghan (1998). Dollaghan found significant group differences for point of target first sound and for the point of isolation in the case of newly taught words. We expected that this might translate into significant group differences for the point of isolation for low-frequency words in this study, suggesting these children's representations of low-frequency words are more holistic when compared with peers. This was not the case; children with SLI were not differently affected by word frequency when compared with peers. Our finding suggests that children's representations of words that are well within their vocabularies are not represented in a holistic manner. It is possible, however, that the low-frequency words in this study were not "low enough." They were obtained from vocabulary counts of 7-year-olds, whereas the children participating in this study were older. It is conceivable that the performance of the two groups might have differed if the words were lower in frequency and if the neighborhood density differences of the stimuli were more extreme. Alternatively, if the children with SLI were younger, we might have found group differences, which would have suggested a slight delay in development of detailed phonological representations of words in SLI.

The current results provide no evidence for the notion that children with SLI have lexical-phonological representations that are more holistic than those of their CA peers. However, this finding does not necessarily mean that children with SLI have lexical representations that are as detailed as those found in typically developing children. Children with SLI may still exhibit less robust, imprecise, or inadequate representations of lexical properties that the word frequency and neighborhood density-adjusted gating task was not suited to reveal; for example, these children's semantic representations may be less detailed.

For point of acceptance, the gate after which the children did not alter the once-identified word, we found significant overall group differences. Children in the SLI group appeared to vacillate between multiple word candidates at significantly later gates when compared with children in the CA group. An additional analysis of nontarget words children produced revealed that children with SLI, like their CA matched peers, were most likely to produce words sharing the beginning target sound. Further, children with SLI more often produced words that bore no apparent phonological relationship to target words, relative to typically developing children. It is unclear at this point what underlies this vacillation and instability. The phenomenon of instability or vulnerability to competition has recently arisen in other studies using different methodologies. When compared with peers, children with SLI have been reported to exhibit poor suppression of unrelated meanings in sentence processing (Norbury, 2005). Children with SLI also experienced greater interference in a nonverbal procedural learning task (Tomblin, Mainela-Arnold, & Zhang, 2007) and greater activation of competing unrelated words in an eye-tracking experiment (McMurray, Samuelson, Lee, & Tomblin, 2006). It appears that vulnerability to competition or lack of inhibition may characterize these children's learning and processing across different modalities. It is also unclear if vulnerability to competition is directly related to the nature of these children's lexical representations. It is possible that the vulnerability to competition is not directly

linked to the specific lexical representations but rather involves some domain general processes, such as attention. Hoffman and Gillam (2004) argued that children with SLI have deficiencies in the executive function of the working memory. In the Baddeley (1992) model of working memory, the central executive is the “attentional controller” responsible for coordinating information from the different slave systems. The concept of central executive as an attentional controller is descriptive rather than explanatory in that it does not explain how the central executive “knows” what to direct the attention to. What are the determinants of attention switching? To what extent does the strength of lexical activations impact attention switching? Finally, the concept of executive function as a part of working memory implies a system that is limited in capacity. The gating task does not involve an apparent memory component that would measure capacity limitation in terms of processing space, and therefore, the concept of executive function does not sufficiently explain the results in this study.

Cowan (1999) has proposed a model of working memory in which attentional control plays a central role and in which capacity limitations in terms of processing space are less important. In his model, working memory capacity reflects the scope of attention, that is, the processes that are attended to in a given task. The developmental changes in processing capacity that occur in childhood are related to “(1) persistence of information that is an activated state, (2) the capacity of the focus of attention, and (3) the rate at which information can be transferred from activated memory to focus of attention” (Cowan, 2003, p. 444). Similarly, current developments in connectionist modeling and neuroscience suggest that what has been referred to as working memory capacity may comprise of global competition of activation in large-scale neural networks with a top-down attentional bias from prefrontal cortex (PFC) circuits (for review, see Maia & Cleeremans, 2005). On one hand, in connectionist models and dynamical systems theory words can be thought of as “attractors” in the child’s “language state space” that differ in their strength of activation (Elman, 1995). Newly emerging skills are more vulnerable to interference effects from competing processes than older, well-learned processes. As learning occurs, skills become sufficiently active, and the magnitude of the competitor effect is altered (Cohen, Dunbar, & McClelland, 1990; Evans, 2007; Magnuson, Tanenhaus, Aslin, & Dahan, 2003). On the other hand, PFC circuits appear to maintain contextual representations that bias the competition between processes and modify the focus of attention quickly and flexibly (e.g., Gray, Chabris, & Braver, 2003; Maia et al., 2005). Thus, contextual task instructions maintained by the PFC activation can influence the outcome of the global competition by biasing network activations associated with the target process.

Given this dynamic developmental view to vulnerability to competition, the results of the point of acceptance analysis and nontarget word analysis are consistent with two possibilities. The first possibility is that something in the lexical representations of children with SLI resembles those of newly learned words in the lexicons of typically developing children. If target lexical items are weakly represented in children with SLI, this means that in lexical access tasks, target stimuli will be more vulnerable to lexical competitors for children with SLI than for their nonimpaired peers. If this is the case, this “something” was not captured by the word frequency and neighborhood density analyses and should be a focus of future research. The second possibility is that children with SLI may experience

weaker contextual PFC activations and therefore less top-down competition bias. With the target word representation not receiving enough biasing activation from the contextual PFC representations, the competing lexical network activations might occasionally end up as the winning network coalition. In either case, we would anticipate low confidence levels in committing to a lexical target—precisely what we observed in the point of acceptance analysis. The nontarget word analysis showed that both children with SLI and typically developing children experienced the most interference from words beginning with similar initial sounds. Furthermore, children with SLI produced proportionally more nontarget words that bore no apparent relationship to the target words than did the CA group. This finding may be explained by the duration-blocked gating format we chose for this study. In the duration-blocked format we presented all 120-ms gates for the words prior to moving on to 180-ms and later gates, in contrast to presenting the different gate durations for each word and then moving to the next word. Given that verbal working memory studies show that children with SLI are more vulnerable to interference from previously presented words (Ellis Weismer, Evans, & Hesketh, 1999), it may be that our children with SLI were vulnerable to competition from words activated prior to the target stimulus. One possible interpretation is that children with SLI experienced more interference from the words they had just said during the previous trial. As the next word was presented at the same gate duration, its activation strength would have to compete with the activation of the word the child had just spoken.

Future research should investigate what governs the functions of inhibition and competition in lexical processing in other tasks in children with SLI. It is essential for us to understand how susceptibility to competition changes as a function of learning and what kind of impairment might produce this susceptibility in children with SLI. Understanding the lack of inhibition in processing and learning may bring us closer to understanding cognitive mechanisms associated with SLI.

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Appendix

Log word frequency (WF) and neighborhood density (ND; number of neighbors) for four categories of target words: (1) high WF, high ND; (2) high WF, low ND; (3) low WF, high ND; and (4) low WF, low ND.

<u>(1) High WF, high ND</u>			<u>(2) High WF, low ND</u>			<u>(3) Low WF, high ND</u>			<u>(4) Low WF, low ND</u>		
Word	WF	ND	Word	WF	ND	Word	WF	ND	Word	WF	ND
Big	6.54	20	Black	5.00	1	Bath	0	17	Beard	0	6
Bike	4.62	19	Blue	4.84	12	Boil	0	15	Blame	0	7
Call	4.41	25	Cold	4.45	11	Cash	0	26	Cough	0	11
Cut	4.14	25	Count	3.91	7	Comb	0	24	Cure	0	1
Fight	4.20	24	Fish	4.91	13	Fur	1.39	20	Fetch	0	8
Hard	5.20	18	High	4.29	9	Heel	0.69	29	Hire	0	5
Hot	5.15	28	House	4.76	5	Hum	1.39	25	Huge	1.79	2
Leaf	4.25	19	Lunch	3.99	7	Lock	0.69	32	Lamp	1.39	11
Name	3.71	16	Move	4.50	8	Nest	0	15	Nurse	0	10
Pick	4.92	34	Play	6.66	3	Poke	0.69	27	Plant	1.10	8
Sit	4.65	36	Soft	4.34	5	Sore	1.61	32	Search	0	11
Work	4.56	20	Watch	5.69	5	Wit	0	31	Wound	0	10
<i>M</i>	4.70	23.70	<i>M</i>	4.82	7.17	<i>M</i>	0.54	24.40	<i>M</i>	0.36	7.50

Note. When defining neighbors for the words, words with an addition, a deletion, or a substitution of one sound were included in the neighborhood. When using the neighborhood calculator, a familiarity criterion of 6 was applied to exclude words with low familiarity ratings from the neighborhoods. Because word frequency and neighborhood density are correlated (e.g., many high-frequency words are also high in neighborhood density), the words were chosen so that the effects of word frequency and neighborhood density can be separated. This was done by making word choices that maintained the following significant and nonsignificant differences: (a) Word frequency for the high WF, high ND words (mean WF = 4.70) and the high WF, low ND (mean WF = 4.82) did not significantly differ, $t(23) = 0.40, p > .05$. (b) Word frequency for the low WF, high ND words (mean WF = 0.54) and low WF, low ND words (mean WF = 0.36) did not significantly differ, $t(23) = 0.80, p > .05$. (c) Neighborhood density for the high WF, high ND words (mean ND = 23.7) and low WF, high ND words (mean ND = 24.4) did not significantly differ, $t(23) = 0.3, p > .05$. (d) Neighborhood density for the high WF, low ND words (mean ND = 7.2) and the low WF, low ND words (mean ND = 7.5) did not significantly differ, $t(23) = 0.23, p > .05$.

Figure 1.
The point of isolation by word frequency (WF) and neighborhood density (ND) for the SLI and CA groups.

Figure 2.
The point of acceptance by word frequency (WF) and neighborhood density (ND) for the SLI and CA groups.

Table 1

The means (*M*), standard deviations (*SD*), age ranges in months, and standardized test scores for the specific language impairment (SLI) and typically developing chronological age-matched (CA) groups.

Group	Age in months	LIPS	ELS	CD	RLS	PPTV	EVT
SLI							
<i>M</i>	120.00	99.88	71.50*	5.65*	67.50	91.25*	81.44*
<i>SD</i>	11.68	8.94	11.62	2.25	14.04	10.75	7.4
Range	101–141	89–119	50–84	3–10	50–86	69–112	64–93
CA							
<i>M</i>	121.25	104	110.06*	12.81*		107.19*	99.38*
<i>SD</i>	13.73	8.31	12.69	2.83		8.53	10.92
Range	101–147	87–119	86–131	8–17		94–119	86–124

Note. LIPS = Leiter International Performance IQ; Standard Score (*M* = 100, *SD* = 15). ELS = Clinical Evaluation of Language Fundamentals: Expressive Language Score (*M* = 100, *SD* = 15). CD = Clinical Evaluation of Language Fundamentals: Concepts and Directions Receptive Standard Subtest Score (*M* = 10, *SD* = 3). RLS = Clinical Evaluation of Language Fundamentals: Receptive Language Score (*M* = 100, *SD* = 15). PPTV = Peabody Picture Vocabulary Test: Standard Score (*M* = 100, *SD* = 15). EVT = Expressive Vocabulary Test: Standard Score (*M* = 100, *SD* = 15).

* $p < .05$, two-tailed *t* test, equal variances assumed.

Table 2

The SLI and CA groups' means (*M*) and standard deviations (*SD*) for the point of target first sound, the point of isolation, and the point of acceptance for the four frequency categories: (a) high word frequency (WF), high neighborhood density (ND); (b) high WF, low ND; (c) low WF, high ND; and (d) low WF, low ND.

Group	High WF, high ND	High WF, low ND	Low WF, high ND	Low WF, low ND
Point of target first sound				
SLI				
<i>M</i>	1.26	1.10	1.15	1.32
<i>SD</i>	0.29	0.13	0.17	0.29
CA				
<i>M</i>	1.47	1.46	1.47	1.57
<i>SD</i>	0.53	0.67	0.64	0.78
Point of isolation				
SLI				
<i>M</i>	5.38	4.18	4.85	5.48
<i>SD</i>	0.55	0.96	0.93	0.74
CA				
<i>M</i>	4.97	4.21	4.66	4.91
<i>SD</i>	0.54	0.70	0.56	0.55
Point of acceptance				
SLI				
<i>M</i>	5.95	5.25	5.90	6.50
<i>SD</i>	0.46	1.07	0.79	0.60
CA				
<i>M</i>	5.58	5.09	5.58	5.65
<i>SD</i>	0.60	0.65	0.61	0.70

Note. The mean values reflect Gates 1 through 10, ranging from 120 to 660 ms in duration.