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Explaining Lexical Semantic Deficits in Specific Language Impairment: The Role of Phonological Similarity, Phonological Working Memory, and Lexical Competition

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Abstract

Purpose—This study investigated potential explanations for sparse lexical-semantic representations in children with specific language impairment (SLI) and typically developing peers. The role of auditory perception, phonological working memory and lexical competition were investigated.

Method—Participants included 32 children (ages 8;5–12;3), 16 children with SLI and 16 typically developing age- and nonverbal IQ matched peers (CA). Children's word definitions were investigated. The words to be defined were manipulated for phonological neighborhood density. Nonword repetition and two lexical competition measures were tested as predictors of word definition abilities.

Results—Children with SLI gave word definitions with fewer content details than children in the CA group. Compared to the CA group, the definitions of children in the SLI group were not disproportionately impacted by phonological neighborhood density. Lexical competition was a significant unique predictor of children's word definitions, but nonword repetition was not.

Conclusions—Individual differences in richness of lexical semantic representations as well as differences between children with SLI and typically developing peers may, at least in part, be explained by processes of competition. However, difficulty with auditory perception or phonological working memory does not fully explain difficulties in lexical semantics.

Keywords

SLI; lexical semantic representation; word frequency; neighborhood density; nonword repetition; lexical competition

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Introduction

Lexical deficits

Children with specific language impairment (SLI) experience difficulties with various lexical processes. This study investigated potential explanations for the lexical semantic difficulties children with SLI face. The underlying deficit causing these difficulties is unknown; these children exhibit difficulty learning spoken words and sentences in the absence of other neurodevelopmental, frank neurological, hearing, emotional or nonverbal intellectual impairments (Leonard, 1998; Tomblin, Records, & Zhang, 1996). Delayed onset of first words is often the first indication of SLI, and children with SLI differ from typically developing peers on estimates of vocabulary size, standardized vocabulary tests, and the number of different words produced in spontaneous language samples (Watkins, Kelly, Harbers, & Hollis, 1995; Bishop, 1997).

Several experimental studies have shown compromised lexical processing in SLI. Children with SLI are slower to recognize words (Edwards & Lahey, 1996) and to name pictures (Lahey & Edwards, 1996; Leonard, Nippold, Kail, & Hale, 1983). Children with SLI also make phonological errors during naming tasks at higher rates than their peers (Lahey & Edwards, 1999). Several studies have shown that on novel word learning tasks children with SLI exhibit difficulties in form-to-meaning mapping (Dollaghan, 1987; Ellis Weismer & Hesketh, 1993; Ellis Weismer & Hesketh, 1996; Oetting, Rice, & Swank, 1995; Rice, Oetting, Marquis, Bode, & Pae, 1994). Children with SLI require as many as two to three times the number of exposures to novel words in order to make gains comparable to their age matched peers (Gray, 2003; Rice et al., 1994). Furthermore, compared to typically developing peers, children with SLI are less likely to retain the newly learned words after a few days have passed (Rice et al., 1994). These children's form-to-meaning mapping ability has also been found to be more susceptible to external perturbations. Ellis Weismer and Hesketh (1993; 1996) reported more adverse effects of fast speaking rates on novel word learning in children with SLI compared to both the age- and language-matched controls. Alt and colleagues (Alt, Plante, & Creusere, 2004; Alt & Plante, 2006) found that preschoolers with SLI encoded fewer semantic features in novel word learning tasks when compared to typically developing peers.

Lexical-semantic deficits

Apart from form-to-meaning mapping in novel word learning paradigms, relatively few studies have investigated lexical-semantic processes in SLI. Marinellie and Johnson (2002) reported that the word definitions of children with SLI reflect a poor understanding of the meaning of common nouns. In a naming experiment by Lahey and Edwards (1999), children with SLI produced more semantically-related errors (e.g. "foot" for "shoe") when compared to typical peers. These results are consistent with results provided by McGregor (1997). Semantic errors were especially prominent for the children with word-finding deficits in her study, which included participants with a wider range of language, speech and fluency disorders. McGregor, Newman, Reilly and Capone (2002) and McGregor and Appel (2002) further analyzed the relationship between naming errors and the richness of word definitions and drawings representing the meaning of the words. They reported that in both groups, SLI and age-matched peers, small amounts of information in definitions and a lack of detail in drawings were associated with both semantic errors and "I don't know" responses. Importantly, McGregor and colleagues reported that children's word definitions and drawings of word meanings yielded consistent results, suggesting that word definitions are a viable window into these children's meaning representations. In sum, these results indicate missing or sparse lexical-semantic representations in children with SLI. It is unclear what underlies the sparse lexical-semantic representations in children with SLI.

Even though current theories of SLI have focused on difficulties with language form rather than semantics, these theories provide possible explanations for the sparse lexical-semantic representations. Several investigators have proposed that the underlying impairment in SLI is an auditory perceptual deficit that would result in poor learning of phonological forms (e.g. Merzenich et al., 1996; Tallal & Piercy, 1973a; 1973b; 1975; 1974; Tallal et al., 1996). Other investigators have argued that the underlying impairment in SLI involves a different type of phonological impairment, namely difficulty processing and storing novel phonological information in phonological working memory (e.g. Gathercole & Baddeley, 1990; Montgomery, 1995; Edwards & Lahey, 1998). Given these proposed core deficits in learning phonological forms, a key question in explaining lexical-semantic difficulties becomes, can difficulties in language form result in difficulties learning the meanings of words?

Developmental association between word forms and semantics

A growing body of research from typically developing children suggests that learning semantic categories is influenced by whether or not a phonological word form is included in the learning environment. Studies with human infants (Graf, Evans, Alibali, & Saffran, 2007) and connectionist models (Joanisse & Seidenberg, 2003) show that earlier experience with phonological forms facilitates future form-to-meaning mapping. Several experiments have shown that the presence of phonological word forms during different semantic category learning tasks facilitates the learning of novel semantic categories (Balaban & Waxman, 1997; Fulkerson & Waxman, 2007; Waxman & Markow, 1995). There is also evidence to suggest that the presence of word forms can even override nonverbal perceptual categories if the word forms are associated with a semantic category organization that is different from the nonverbal categories (Plunkett, Hu, & Cohen, 2008). Plunkett and colleagues (2008) presented typically developing children with specially constructed pictures of cartoon animals. The visual features of the animal pictures were manipulated such that children exposed to these pictures extracted and learned two visual categories of animals in a learning condition where word forms were not present (e.g. children categorized animals with long necks as one kind and animals with short necks were another kind). However, in a condition where word forms were presented with the pictures, children's visual semantic learning was different. When the same visual stimuli were presented with a word form that labeled all the pictures with a single category label (e.g. both long and short necked animal pictures were presented with the word "dax"), the children learned only one semantic category (e.g. instead of long necked and short necked animals, children categorized the animals as belonging to the same category). Essentially, the presence of the word from overrode the visual tendency to semantically categorize the animals as two different kinds, suggesting that the presence of word forms has a decisive impact on semantic category learning.

Since the presence or absense of phonological forms has been shown to impact semantic category learning in typically developing children, and since it has been proposed that the core deficit in SLI has to do with learning phonological forms rather than semantic categories per se, it is possible that factors primarily related to phonological learning underlie difficulties learning lexical-semantics. It is possible that a primary difficulty with phonological word forms results, over the course of the development, in degraded semantic representations.

Deficits in auditory perception

Various types of difficulties with learning phonological forms in SLI have been proposed. One possibility is that the underlying impairment SLI is an auditory perceptual deficit (e.g. Merzenich et al., 1996; Tallal et al., 1973a; 1973b; 1974; 1975; Tallal et al., 1996).

Presumably this auditory perceptual deficit would result in difficulty learning phonological forms (Stark & Heinz, 1996b; 1996a). It is possible that difficulty differentiating between phonological forms of words underlies the lexical semantic problems of children with SLI. Consider a hypothetical child who has difficulty differentiating between the auditory forms of the words “bowl” and “pole.” The child perceives /_ol/ sometimes associated with bowls and sometimes with poles. Given that presence of word forms have a decisive impact on nonverbal categorization (e.g. Plunkett et al., 2008), it is conceivable that this child would experience difficulty learning the semantics of the two words.

The notion that difficulty differentiating between phonological forms underlies lexical semantic difficulties in SLI can be examined by investigating the effects of phonological neighborhood density. The concept of neighborhood density refers to the number of similar sounding words in a language, or in practice, in a language corpus. It reflects a view of word recognition as a process of discriminating among competing lexical representations that share similar phonological properties (Luce & Pisoni, 1998). Words that share similar phonological features are considered phonological neighbors (e.g. bowl and pole). Neighborhood density influences word recognition in adults. Adults are faster and more accurate at recognizing words that come from sparse neighborhoods, and slower and less accurate at recognizing words that come from dense neighborhoods (Garlock, Walley, & Metsala, 2001; Luce et al., 1998; Vitevitch & Luce, 1998; 1999).

Effects of neighborhood density are present in children as well. Developmentally, the effects of phonological neighborhood density on lexical processing appear to be emergent. The inhibitory effects of high neighborhood density in word recognition tasks are smaller in elementary school-aged children than in adults (Metsala, 1997a; 1997b; Garlock et al., 2001). Younger preschoolers, on the other hand, show no significant effects of neighborhood density in word recognition tasks (Garlock et al., 2001). Further evidence for the developmental emergence of these effects comes from word repetition in preschoolers: preschoolers exhibit effects of neighborhood density in repeating early-acquired words, but not in repeating later-acquired words (Garlock et al., 2001; Metsala, 1997b). Charles-Luce and Luce (1990; 1995) present an explanation for the emergent effect of neighborhood density. Their analysis of young children’s vocabularies showed that the phonological neighborhoods of young children are sparsely populated. Learning more words presumably forces the addition of more phonological detail to lexical representations as phonological neighborhoods become more densely populated. Storkel (2002) reports effects of neighborhood density on preschool children’s performance on a similarity classification task, suggesting that in preschool children’s vocabularies, words in sparse neighborhoods are represented with less detail than words in dense neighborhoods.

In conclusion, an essential mechanism for learning new words in childhood involves discriminating similar-sounding words in the language learning environment and storing them with sufficient phonological detail. Since the presence or absence of phonological forms shapes the development of children’s semantic representations, it is conceivable that a difficulty in discriminating between similar sounding words might lead to difficulty in establishing robust, detailed semantic representations.

Deficits in phonological working memory

Other investigators have argued that the underlying impairment in SLI involves a different type of phonological impairment, namely difficulty processing and storing novel phonological information in phonological working memory (e.g. Gathercole et al., 1990; Montgomery, 1995; Edwards et al., 1998). Gathercole and Baddeley (1990) argue that deficits in the ability to maintain phonological information in working memory result in the language impairments in SLI. According to their model, working memory is divided into components: the central executive, the visuospatial sketch pad, and the phonological loop. The central executive is the “attentional controller” responsible for coordinating information from the phonological loop and the visuospatial sketch pad. In this model, phonological working memory is comprised of the central executive and the phonological loop – the slave system responsible for maintaining a phonological representation of a novel word in phonological working memory (Baddeley, 1992; Gathercole et al., 1990).

The paradigm traditionally used to assess phonological working memory in children is a task where children repeat multi-syllabic nonsense words: nonword repetition. There is a large body of research linking nonword repetition performance and vocabulary in typically developing children (e.g., Bowey, 1996). Studies have also shown that children with SLI are significantly poorer than their peers in their ability to repeat nonsense words (Bishop, North, & Donlan, 1996; Dollaghan & Campbell, 1998; Edwards et al., 1998; Gathercole et al., 1990; Montgomery, 1995). Further, results suggest that nonword repetition tasks may be a culturally unbiased, reliable diagnostic indicator of a language disorder (Dollaghan et al., 1998; Ellis Weismer et al., 2000) and it has even been argued that performance on nonword repetition tasks may be a phenotypic marker of SLI (Bishop et al., 1996).

Gathercole (2006) argues that both nonword repetition and vocabulary learning share a core mechanism of temporary storage of phonological representations. Reduced capacity of this temporary storage would, in the case of SLI, lead into reduced vocabulary learning, as measured by traditional receptive vocabulary measures that require perceiving a word and mapping it onto a semantic representation. However, this line of work has not specified if and how this ability to temporarily store phonological representations would affect the development of semantic representations in particular. Since we have evidence suggesting that the presence or absence of phonological forms shapes the development of children’s semantic representations, it is conceivable that difficulty processing and maintaining novel phonological sequences may underlie lexical semantic difficulties in SLI. Difficulty maintaining novel phonological forms in working memory could result in difficulty processing and learning semantic features associated with the phonological form.

Difficulties with resolving lexical competition

Recent experiments studying word recognition processes in children with SLI have proposed yet another type of lexical difficulty in children with SLI. Mainela-Arnold, Evans and Coady (2008) presented children with SLI with a forward gating task. In this task, children hear acoustic chunks (i.e., gates) of words, starting from the beginning and increasing in length. Children are asked to guess the word after each gate. Mainela-Arnold and colleagues found that children with SLI did not differ from their peers in the ability to perceive initial sounds and activate the target words in their lexicons, as evidenced by comparable amounts of acoustic information needed to first activate words with the same initial phoneme, or the actual target words, respectively. However, group differences were evident in the ability to commit to a correctly identified target words. Children with SLI were more likely to change their word guesses when they heard larger acoustic chunks of the words, and they produced significantly more non-target competitors. This suggests that children with SLI do not have problems with perceiving and activating lexical phonological forms based on acoustic phonological information during lexical access. Instead, these children appeared to experience difficulty inhibiting activations of non-target competitor words.

Recent evidence indicates that compared to typically developing controls, children with SLI exhibit poor performance in several classic measures of attention and inhibition (Finneran, Francis, & Leonard, 2007; Im-Bolter, Johnson, & Pascual-Leone, 2006; Spaulding, Plante, & Vance, 2007). Children with SLI exhibit a larger stroop-interference effect on the color-word Stroop task (Im-Bolter et al., 2006). Children with SLI also exhibit difficulty inhibiting prepotent eye movements on a visual spatial antisaccade task and inhibiting competitor responses on verbal a set-shifting task (Im-Bolter et al., 2006). Difficulties with both correct hit rates and false alarms in simple verbal and nonverbal go-no go tasks, and difficulties with inhibiting auditory and linguistic distracters have also been reported (Finneran, Francis, & Leonard, 2007; Spaulding, Plante & Vance, 2007). To summarize, poor attention or inhibition characterizes these children's processing across different modalities. By *attention* we refer to a shift of focus to relevant lexical or perceptual activations guided by the context (e.g. maintaining and shifting focus based on the task instructions in the go-no go task to "press a button when you see a square, but don't press a button when you see a triangle"). By *inhibition* we refer to the subsequent blocking of irrelevant competing lexical or perceptual activations (e.g. inhibiting irrelevant distracter stimuli on a visual antisaccade task).

Mainela-Arnold and colleagues (2008) argued that recent advances in connectionist modeling and neuroscience may offer explanations for associations between inhibition, attention and lexical processes in SLI, including the finding described earlier - that children with SLI seemed to have difficulty inhibiting lexical competitors in the gating task. What has been traditionally viewed as working memory capacity may comprise 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). Words are conceived as "attractors" in the child's "language state space", differing in their strength of activation (Elman, 1995). Newly emerging attractors are more vulnerable to competing processes than older, established processes (Evans, 2008; Magnuson, Tanenhaus, Aslin, & Dahan, 2003). It is possible that the greater level of competitor activation in lexical access seen in SLI is a result of lexical representations that resemble those of newly established lexical attractor states in the lexicons of typically developing children, resulting in poor *inhibition* of competitor words. An alternative possibility is that children with SLI may suffer from weaker top-down *attentional* PFC activations (Ellis Weismer, Plante, Jones, & Tomblin, 2005) and therefore less contextual top-down attentional competition bias, resulting in difficulty with top-down maintenance of the focus of attention. If the phonological forms of the target word representation are not receiving enough biasing attentional activation from the contextual PFC representations, the winning network coalition may occasionally be a competing lexical network activation.

It is conceivable that difficulties with lexical phonological competition during word recognition (either in the form of insufficient inhibition of competing lexical activations or insufficient contextually driven focus of attention) would result in degraded semantic representations in children with SLI. If multiple competing phonological word forms remain active during word recognition, it may be that learning semantic features associated with the phonological form are compromised.

Current Study

In the current study, we set out to investigate what might underlie lexical-semantic difficulties in SLI. Given that auditory perceptual deficits, limited phonological working memory capacity and difficulties with lexical competition have been implicated as potential deficits in SLI, we considered three competing hypotheses: Lexical-semantic difficulties in SLI would be explained by (1) difficulty differentiating similar sounding words in the language-learning environment, (2) difficulty maintaining and processing novel phonological forms in working memory, or (3) difficulty with attention or inhibition. The questions to be answered were: (1) Do children with SLI, when compared to age-matched peers, exhibit difficulty defining words that are phonologically similar to many other words in the language-learning environment? If children with SLI exhibit disproportionate difficulty defining words which are phonologically similar to many other words in their learning environments, semantic difficulties in SLI can, at least in part, be explained by difficulty differentiating similar sounding words. (2) Does the ability to repeat nonsense words predict lexical semantic abilities in children with and without SLI? If children's word definition skills are predicted by their nonsense word repetition abilities, then semantic difficulties can, at least in part, be explained by difficulty maintaining phonological forms in working memory. (3) Do difficulties with lexical competition predict lexical semantic abilities in children with and without SLI? If children's word definition skills are predicted by their ability to attend to relevant lexical processes or inhibit competing ones, semantic difficulties can, at least in part, be explained by processes of lexical competition.

Methods

Participants

The participants were 32 children between the ages of 8;5 and 12;3. Sixteen of the children had SLI and 16 were typically developing, matched by chronological age and nonverbal IQ (CA). A group-wise matching criterion of +/− 9 months and +/− 7 standard nonverbal IQ points was used. The children were recruited from schools in the Madison, Wisconsin area.

All the participating children were required to meet the following inclusion criteria: (1) Performance Intelligence Quotient above 85 as measured by Leiter International Performance Scale (LIPS; Roid & Miller, 1997) (2) pass a pure tone hearing screening at 500, 1000, 2000, & 4000 Hz and 20 dB HL, (3) normal oral and speech motor abilities as observed by a certified speech-language pathologist, and (4) monolingual, English speaking home environment.

The exclusion criteria for this study were: (1) neurodevelopmental disorders other than SLI, (2) emotional or behavioral disturbances, (3) motor deficits or frank neurological signs, or (4) seizure disorders or use of medication to control seizures. Parental report was used to confirm that the children had not been diagnosed with any of these conditions.

A battery of standardized language tests was administered to all children. The Clinical Evaluation of Language Fundamentals, Third Edition (CELF-3; Semel, Wiig, & Secord, 1995) was used to assess receptive and expressive language skills. The Peabody Picture Vocabulary Test, Third Edition (PPVT-III; Dunn & Dunn, 1997) was used to assess receptive vocabulary and the Expressive Vocabulary Test (EVT; Williams, 1997) was used to assess expressive vocabulary. The results for the standardized testing are presented in Table 1.

Children were included in the SLI group if they received a score of 1.25 *SD* or more below the mean for one or more of the following tests: CELF-3 Expressive Language Score, CELF-3 Receptive Language Score, PPVT-III standard score, or EVT standard score. Children were included in the CA group if they received a standard score higher than 1.00 *SD* below the mean on all of the following: CELF-3 Expressive Language Score, CELF-3 Concepts and Following Directions, PPVT-III, and EVT. Furthermore, typically developing children were also required to have no history of services to treat speech, language or learning disabilities.

Compared to typically developing children, children in the SLI group received significantly lower scores on all of the language measures. Children with SLI scored lower than CA peers on the CELF-3 Expressive Language Scale, $t(df=30) = 8.97$, $p < .05$, the CELF-3 Concepts and Following Directions, $t(df=30) = 8.00$, $p < .05$, the PPTV-III, $t(df=30) = 4.65$, $p < .05$, and the EVT, $t(df=30) = 5.43$, $p < .05$. The two groups did not differ significantly on nonverbal IQ as measured by LIPS performance IQ, $t(df=30) = 1.35$, $p > .05$.

The SLI group consisted of 11 White, three African-American, and two biracial children. The CA group consisted of 15 White and one African-American child.

Stimuli

Words—A set of 48 monosyllabic target words was selected based on neighborhood density, word frequency and initial sounds. The word frequency counts were obtained from the spoken vocabulary of first grade children studied by Moe et al. (1982). The neighborhood density counts were obtained from the Washington University in St. Louis Speech and Hearing Laboratory neighborhood density calculator available online at http://128.252.27.56/neighborhood/Home.asp. The calculator bases its counts on the Hoosier Mental Lexicon (Nusbaum, Pisoni, & Davis, 1984) with word frequency counts from the Brown corpus (Kucera & Francis, 1967). In order to investigate effects of neighborhood density independent of word frequency, four frequency categories were created, resulting in 12 words in each category:(1) high word frequency (WF), high neighborhood density (ND); (2) high WF, low ND, (3) low WF, high ND and (4) low WF, low ND. All four categories contained nouns, verbs and adjectives. More information on the choice of words, their frequency counts, and the balancing of the frequency counts can be found in Mainela-Arnold et al. (2008).

The stimuli were read by a female speaker with an upper Midwestern accent in a sound-attenuated chamber. A Windows-based program was used to digitally record the words at a 44.1-kHz sampling rate with 16-bit resolution.

Definition task—For the definition task, the words were recorded and presented to the children in a carrier question (e.g. “What is a nest?”). See Appendix A for the stimulus sentences presented to the children.

Lexical competition measures—Two additional lexical tasks that used the stimulus words were presented to the children. They involved (1) inhibiting competitor words (forward gating task) and (2) delaying lexical verbal responses according to task instructions (delayed repetition task). For the *forward gating task,* each of the 48 words was presented in ten gates of increasing size. Gates at 120, 180, 240, 300, 360, 420, 480, 540, 600, and 660 ms starting from the beginning of the word were created. More information on the gated stimuli can be found in Mainela-Arnold et al. (2008). For the *delayed repetition task*, PsyScope was programmed to present the 48 target words twice, once with a 300 ms delayed response signal and once with a 1000 ms delayed response signal. The delayed response signal was a pure tone.

Nonword Repetition—As a measure of phonological memory, children participated in a nonword repetition task, originally described by Dollaghan and Campbell (1998). Their version of the task includes 16 nonwords one to four syllables in length. Nonwords contain early-acquired phonemes but in infrequently-occurring syllable positions. Gathercole (1995) reported that children’s repetition of nonwords judged to be low in word-likeness correlated with another measure of phonological memory, digit span, while their repetition of nonwords high in word-likeness correlated with a standardized measure of receptive vocabulary. Because the Dollaghan and Campbell nonwords are minimally word-like, having children repeat them is usually considered a relatively pure measure of phonological memory. Previously recorded nonwords were presented in a fixed order in blocks of increasing length. Children were told that they would be hearing funny, made-up words, and their job was to repeat them back as quickly and accurately as possible. The task took approximately one minute, and children’s repetitions were recorded for subsequent transcription.

Procedure

Children completed the standardized testing and the nonword repetition task during three earlier visits to the Child Language and Cognitive Processes Laboratory. The gating task was presented on a subsequent visit together with a categorical perception task (Coady, Evans, Mainela-Arnold, & Kluender, 2007). A final visit included various tasks that were parts of other studies: a sentence span task (Mainela-Arnold, Evans, & Coady, in press), a simple word span task, the delayed repetition task, a priming task, and the definition task. The sessions lasted approximately one and a half hours including a snack break half-way through the session.

Definition task—The children were asked to explain what different words mean as they would to a person who did not know what the words meant. The children defined four practice words. All children explained word meanings appropriately during the practice.

The words were presented in four clusters, each containing 12 words. Each of the four clusters contained three randomly chosen words from the four frequency categories (i.e., 4 clusters × 3 words × 4 frequency categories = 48 words). We counterbalanced the order of the presentation of four clusters over the two groups. The stimuli were presented on a computer through headphones. The stimuli were repeated if a child requested a repetition. Children were given as long as they needed to define the words. Children's responses were recorded using a Sony minidisc recorder and an external lavalier microphone. Completion of the definition task took approximately 15 minutes. Between the four clusters of 12 stimuli, children were offered short breaks.

Children's word definitions were transcribed orthographically from the audiotapes. Based on the transcripts, children's responses were coded using a system developed by Astell and Harley (2002). Table 2 presents the coding system and examples from the dataset. This coding system reflects the semantic richness of children's lexical representations and but with little emphasis on the partially metalinguistic ability to produce formal definitions. Furthermore, the raters were instructed to score children's understanding of the semantics of the word but to ignore any difficulties with language form. Departing from the Astell and Harley system, group ratings were used given the subjective nature of the coding system. Five students majoring in communication disorders (three undergraduate and two clinical master's students) rated children's definitions. Therefore, each child's semantic scores were means derived from five different raters' judgments. Raters had completed a minimum of two courses in child language development and disorders. They were blind to both the hypotheses of the study and the child's group assignment. To assess the reliability of this measure, correlations between each rater's mean scores for all children were examined. As can be seen in Table 3, the correlations between the raters varied from $r = .87$ to $r = .96$.

Nonword Repetition—Children's repetitions were phonetically transcribed from recordings of their experimental sessions and scored using a consensus method. Two different listeners blind to children's language status each completed a first-pass transcription, their results were compared, and a third listener mediated any disagreements. Percent phonemes correct was then calculated as the number of target phonemes correctly produced divided by the total number of target phonemes. As described by Dollaghan and Campbell (1998), only phoneme deletions or substitutions counted as errors. Phoneme additions did not affect children's final scores because they do not represent the loss of any information.

Inhibition: A measure from the gating task—Children were asked to play a guessing game where they would hear pieces of words, and try to guess the word after each piece.

Children's responses were recorded and transcribed orthographically after each gate duration. Number of non-target competitor words children produced, i.e. words that were different from the gated stimuli words, were determined. More information on the gating task procedure, including coding reliability estimates, can be found in Mainela-Arnold et al. (2008).

Attention: Following contextual task directions of delaying a verbal response during a delayed repetition task—The children were asked to play a speed naming game where they heard words and repeated them after having to wait for a response signal with a long delay or a short delay. Four practice words, each with a long and short delay before the response signal, were presented to the children. All children were able to appropriately wait for the response signal and repeat the practice words. The stimuli were presented using the PsyScope computer program. Children heard the stimuli through head phones. PsyScope was programmed to present each of the 48 target words once with a 300 ms delayed response signal and once with a 1000 ms delayed response signal. The program presented the words and the delays in a pseudo-random order. Children's responses were recorded using Sony minidisc recorder and external lavalier microphone. Only responses after the 1000 ms delay were transcribed from the audiotapes and coded as either correctly waiting for the response signal or failing to wait for the response signal. To establish the reliability of this measure, a second researcher coded 15% of children's responses, including an equal number of responses from the SLI and CA groups. Point to point reliability of this measure was 100%.

Results

Phonological neighborhood density

We first investigated if children's definitions were influenced by the phonological neighborhood density or frequency of the word to be defined. The means and standard deviations for these variables are presented in Table 4. These descriptive data show that while there appeared to be an overall group difference in the definition scores, the frequency structure profiles were similar for both groups. In the case of high frequency words, both high and low density words were defined equally well, but in the case of low frequency words, definition scores for low density words were higher than definition scores for the high density words.

We performed a Group × Word Frequency × Neighborhood Density ANOVA with semantic score as the dependent variable. The only significant group difference was the main effect of group, $F(1, 30) = 15.26$, $p < .05$, $\eta^2 = .34$, *power* = .97. Children with SLI had lower word definition scores overall than CA peers. However, the group interactions with word frequency and neighborhood density did not reach significance. Group × Word Frequency × Neighborhood Density, $F(1, 30) = .75$, $p > .05$, $\eta^2 = .02$, *power* = .13, Group × Neighborhood Density, $F(1, 30) = .50$, $p > .05$, $\eta^2 = .02$, *power* = .11, and Group × Word Frequency, $F(1, 30) = .20$, $p > .05$, $\eta^2 = .01$, *power* = .07 were all non-significant, indicating no group differences in the effects of neighborhood density or word frequency on children's definition scores.

We did, however, find effects of phonological frequency structure for the two groups combined. A significant Word Frequency x Neighborhood Density interaction was found, $F(1, 30) = 12.51$, $p < .05$, $\eta^2 = .29$, *power* = .93. In the case of high frequency words, the effect of neighborhood density was not significant, $F(1, 30) = .31$, $p > .50$. In the case of low frequency words, definition scores for words with many neighbors were significantly lower than for words with few neighbors, $F(1, 30) = 26.90$, $p < .05$. A significant main effect of neighborhood density was also found, $F(1, 30) = 11.74$, $p < .05$, $\eta^2 = .28$, *power* = .91, indicating that for both groups, definition scores for words with many neighbors were significantly lower than for words with few neighbors. The main effect of word frequency did not reach significance, $F(1, 30) = 2.23$, $p > .05$, $\eta^2 = .07$, *power* = .30.

Since our measure of semantic representations involved sentence formulation, we considered the possibility that the observed group difference was due to group differences in sentence formulation abilities. An ANCOVA with Formulated Sentences standard subtest score from the CELF-3 as a covariate was performed. The group difference in semantic scores remained significant even when Formulated Sentences was entered as a covariate, $F(2, 29) = 4.30$, $p < .05$, indicating that sentence formulation abilities did not account for group differences in semantic scores.

For the question of whether the quality of semantic representations in SLI is affected by neighborhood density, it would have been beneficial to better control for grammatical class and imageability of the words presented to the children. In order to gain some perspective if these factors might have contributed to the results, two additional post hoc analyses were conducted. We determined imageablity estimates for the words in the four frequency categories using the MRC database available on line at http://www.psy.uwa.edu.au/mrcdatabase/uwa_mrc.htm (Coltheart, 1981). Estimates were available all words except for one word in the high WF, high ND category, four words in the low WF, high ND category and four words in the WF, low ND category. For the words with missing MRC estimates, estimates on the same scale were obtained from the Bristol (Stadthagen-Gonzalez.H. & Davis, 2006), Bird (Bird, Franklin, & Howard, 2001) or Cortese (Cortese & Fugett, 2004) norms. Using these estimates, the words in the four frequency categories did not significantly differ in imageability, High WF, Low ND, *mean* = 507.58, *SD* = 67.98, High WF, Low ND, *mean* = 528.83, *SD* = 67.66, Low WF, High ND, *mean* = 511.50, *SD* = 103.60, Low WF, Low ND, *mean* = 499.75, *SD* = 104.42, $F(3, 48) = .24$, $p = .87$. Furthermore, we investigated if children's word definition scores for nouns, adjectives and verbs were significantly different apart from word frequency and neighborhood density. In the context of this study, children's word definition scores for nouns, adjectives and verbs did not significantly differ for either group, the SLI, noun *mean* = 2.50, *SD* = .77, adjective *mean* = 2.25, *SD* = .34, verb *mean* = 2.36, *SD* = .31, $F(2, 48) = .67$, $p = .52$, or the CA, noun *mean* = 3.01, *SD* = .73, adjective *mean* = 3.05, *SD* = .30, verb *mean* = 3.00, *SD* = .36, $F(2, 48) = .06$, $p = .94$. This suggests that imageability and grammatical class were unlikely to have had a major impact on the results.

Phonological working memory and lexical competition as predictors

We then considered potential predictors of children's lexical semantic skills. Three potential predictors of children's semantic scores were considered: nonword repetition and two measures of lexical competition: inhibition (competitor words activated during the gating task) and attention (following contextual task directions of delaying a verbal response during the delayed repetition task). Table 5 presents the descriptive statistics for these variables. The two groups differed significantly in all three of the predictor variables. Group comparisons on these variables showed that children with SLI repeated nonwords significantly less accurately (nonword repetition), $F(1, 30) = 17.12$, $p < .05$, $\eta^2 = .36$, *power* = .98 than CA peers, activated significantly more non-target competitor words in the gating task (Inhibition, Mainela-Arnold, Evans, & Coady, 2008), and failed to wait for the response signal significantly more often (attention), $F(1, 30) = 6.75$, $p < .05$, $\eta^2 = .18$, *power* = .71. Table 6 presents the correlations between the predictor variables and the semantic scores for the two groups combined. Two of the predictors, nonword repetition, $r = .41$, $p < .05$, and attention, $r = .62$, $p < .05$, correlated significantly with children's semantic scores. Inhibition did not significantly correlate with semantic scores, $r = -.18$.

Multiple regression analyses were conducted to investigate the impact of the predictor variables on the semantic scores. Since the distribution of semantic scores in the two groups combined approximated the normal distribution and the residual plots indicated homoscedasticity, untransformed raw scores were used. Two models were considered. For both models, age and CELF-III Formulated Sentences standard score were entered in the first step to control for potential effects of age and sentence formulation abilities. In the first model, nonword repetition was entered in the second step and the two lexical competition variables were entered in the third step. In the second model, the two lexical competition variables were entered in the second step and the nonword repetition was entered in the third step. The dependent variable was semantic score.

Multiple Regression Model 1—The control variables accounted for a significant proportion of the variance, $F(2, 29) = 5.66$, $p < .05$. Twenty eight percent of the variance in semantic scores was accounted by age and Formulated Sentences combined. While age was not significantly associated with children's semantic scores, $\beta = -.01$, $t = .99$, $p = .92$, Formulated Sentences was, $\beta = .54$, $t = 3.17$, $p < .05$. Adding nonword repetition in the second step did not result in a significant R^2 change, from step 1 to step 2, F change = 1.18, $p = .29$. This suggests that nonword repetition did not account for any additional variance in semantic scores beyond sentence formulation abilities and age. However, adding the lexical competition predictors in the third step resulted in a significant model, $F(5, 26) = 5.46$, $p < .05$, with a significant R^2 change from step 2 to step 3, F change = 5.39, $p < .05$. Step 3 accounted for 51% of variance in semantic scores, indicating that the lexical competition measures accounted for a significant proportion of variance (23%) independent from nonword repetition, Formulated Sentences and age. Inspection of the standardized β-coefficients indicated that attention was a significant predictor of semantic scores, $\beta = .41$, $t = 2.47$, $p < .05$. Inhibition, however, did not reach significance as a predictor, $\beta = .21$, $t = .91$, $p = .37$.

Multiple Regression Model 2—Even though nonword repetition did not account for any variance beyond sentence formulation abilities in Model 1, Model 2 was run for the sake of completeness. In model 2, the R^2 change from step 1 to step 2 (entering lexical competition variables after the control variables age and Formulated Sentences) resulted in a significant F change, F change = 5.64, $p < .05$, confirming that lexical competition measures accounted for variance in semantic scores independent from age and sentence formulation abilities. However, the R^2 change from step 2 to step 3 (entering nonword repetition) was not significant, F change = 1.02, $p < .05$, confirming that nonword repetition did not account for any additional variance in semantic score independent from the lexical competition measures.

Discussion

This study investigated potential mechanisms contributing to richer or more sparse lexical-semantic representations in children with and without SLI. Three possibilities were considered. (1) Children with SLI exhibit difficulty learning lexical-semantics because they experience difficulties differentiating between phonologically similar words in the language learning environment. (2) The ability to process and store novel phonological forms in working memory contributes to learning of semantics in children with and without SLI. (3) The ability to attend to relevant processes and to inhibit competing lexical phonological activations contributes to semantic learning in children with and without SLI.

Consistent with previous research (Marinellie & Johnson, 2002; McGregor, Newman, Reilly, & Capone, 2002), children with SLI exhibited word definitions that were indicative of sparser semantic representations compared to age-matched peers. An ANCOVA indicated that this group difference was not simply due to sentence formulation abilities required for the definition task. In an attempt to explain this group difference in lexical semantic skills, we first conducted an analysis investigating whether the number phonologically similarity words has an impact on the richness of children's word definitions. An ANOVA indicated the children with SLI did not exhibit disproportionate difficulty defining words that have many phonologically similar words in the lexical learning environment. Children in both groups gave richer definitions for words that came from sparse as opposed to dense neighborhoods, but both groups were affected by the phonological frequency structure to the same degree. This result was inconsistent with the first hypothesis, suggesting that even though children's semantic learning in general appears to be influenced by the number of phonologically similar words, the semantic difficulties of children with SLI may not be explained by a particular difficulty with auditory discrimination of phonologically similar words.

Secondly, we investigated potential predictors of children's word definition scores. A multiple regression analysis indicated that both sentence formulation and nonword repetition abilities were associated with children's word definition scores. However, nonword repetition did not predict any variance independent from sentence formulation abilities. It is not surprising that sentence formulation abilities accounted for variance in word definition scores. Marinellie and Johnston (2002) report difficulties in the mastery of producing the form of word definitions in addition to difficulties with word semantics. What was surprising, however, was that nonword repetition did not explain variance beyond sentence formulation abilities. One might argue that these children's semantic skills might have been affected by their phonological working memory capacity when they were younger, but at this older age, the effects are no longer present. This is consistent with work by Gathercole and colleagues, who reported that associations between children's vocabulary knowledge and nonword repetition were stronger during preschool years than at age 8 (Gathercole, Willis, Emslie, & Baddeley, 1992). An inspection of correlations in Table 6, however, suggests that controlling for age did not reduce the correlation between definition scores and nonword repetition, but controlling for Formulated Sentences did. This suggests that controlling for sentence formulation abilities rather than age explained the lack of unique variance accounted for by nonword repetition. An interpretation of these results is that processing and retaining novel phonological forms during the nonword repetition task may not account for individual differences in children's word definition abilities. Instead, nonword repetition and sentence formulation both involve a shared mechanism of speech and language production. This interpretation is consistent with Coady and Evans' (2008) recent doubts regarding the viability of the construct of phonological working memory separate from linguistic knowledge. Gray (2006) similarly found few associations between receptive vocabulary, phonological working memory, and novel word learning in children with and without SLI. The ability to process and store phonological forms in working memory may not explain lexical-semantic difficulties.

Interestingly, out of the two lexical competition measures, attention, or the ability to delay a verbal response according to task instructions, was a significant predictor of children's word definitions. Attention accounted for unique variance in definition scores independent of age, sentence formulation and nonword repetition abilities. This highlights a possibility that attentional abilities and lexical semantics skills are strongly related.

This study has limitations related to the choice of the word definition task as a measure of semantic abilities and to controls for the properties of the word stimuli. It would have been beneficial to choose a task that measured semantic abilities apart from mastery of definitional forms. Consequently, we may have somewhat underestimated children's semantic knowledge. However, we do believe that the word definitions in our study were reasonable estimates of these children's semantic representations. McGregor et al. (2002) report that for groups of children with SLI and typical development similar to ours, word definitions and drawings of word meanings yielded consistent results for the majority of children. It would also have been beneficial to better control the stimulus words for grammatical class and imageability. In the context of this study, more thorough control for these variables was not feasible (for discussion on this issue see Cutler, 1981). However, our post hoc analysis investigating the potential effects of these variables suggested that the results were not materially affected by these factors.

It is not well understood why individual differences in attention might be associated with individual differences in the richness of children's lexical-semantic representations. There are at least two possible explanations for this association. It may be that in elementary school age children, primary phonological difficulties present themselves as a difficulty attending to relevant lexical processes. It is conceivable that poorly defined lexical representations result in poor attention, i.e. that sparse lexical representations lead to difficulty attending to relevant lexical processes. However, the results of this study support more directly the possibility that primary attentional problems result in difficulty attending to relevant cues and inhibiting irrelevant cues in the language learning environment. This, in turn, may result in poor learning of word semantics. However, before we declare that deficits in attention underlie lexical semantic deficits in SLI, future investigations should take a developmental perspective on the issue. Which comes first, poor ability to attend to relevant cues and inhibit irrelevant cues, or poor lexical semantic skills?

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APPENDIX A

Stimuli for the word definition task. The words to be defined were (1) High Word Frequency (WF), high Neighborhood Density ND, (2) High WF, ND, (3) Low WF, high ND, (4) Low WF, low ND. The procedures followed in creating the stimuli words, including word frequency and neighborhood density counts, are published in Mainela-Arnold et al. (2008). The counts were for established for the roots of words. Sentences were used to indicate the intended word class.

(1) High WF, high ND stimuli	*(2) High WF, low ND stimuli*
What does big mean?	What does black mean?
What does biking mean?	What does blue mean?
What does calling mean?	What does cold mean?
What does cutting mean?	What does counting mean?
What does fighting mean?	What does fishing mean?
What does hard mean?	What does high mean?
What does hot mean?	What is a house?
What is a leaf?	What is lunch?
What is a name?	What does moving mean?
What does picking mean?	What does playing mean?
What does sitting mean?	What does soft mean?
What does working mean?	What does watching mean?
(3) Low WF, high ND stimuli	*(4) Low WF, low ND stimuli*
What is a bath?	What is a beard?
What does boiling mean?	What does blaming mean?
What is cash?	What does coughing mean?
What does combing mean?	What does curing mean?
What is fur?	What does fetching mean?
What is a heel?	What does hiring mean?
What does humming mean?	What does huge mean?
What is a lock?	What is a lamp?
What is a nest?	What is a nurse?
What does poking mean?	What is a plant?
What does sore mean?	What does searching mean?
What is wit?	What is a wound?

Table 1

Ages and standardized test scores for the SLI and CA groups presented as means, standard deviations (SD) and ranges.

Group	Age in months	LIPS[a]	ELS[b]	CD[c]	RLS[d]	PPTV[e]	EVT[f]
SLI							
Mean	120.00	99.88	71.50*	5.65*	67.50	91.25*	81.44*
SD	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							
Mean	121.25	104	110.06*	12.81*	Na	107.19*	99.38*
SD	13.73	8.31	12.69	2.83	Na	8.53	10.92
Range	101–147	87–119	86–131	8–17	Na	94–119	86–124

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

[a] Leiter International Performance IQ: Standard Score (mean of 100, standard deviation of 15)

[b] Clinical Evaluation of Language Fundamentals: Expressive Language Score (mean of 100, standard deviation of 15)

[c] Clinical Evaluation of Language Fundamentals: Concepts and Directions receptive standard Subtest Score (mean of 10, standard deviation of 3)

[d] Clinical Evaluation of Language Fundamentals: Receptive Language Score (mean of 100, standard deviation of 15)

[e] Peabody Picture Vocabulary Test: Standard Score (mean of 100, standard deviation of 15)

[f] Expressive Vocabulary Test: Standard Score (mean of 100, standard deviation of 15)

Table 2

The coding system (Astell & Harley, 2002) and examples of children's definitions

Score	**0**	**1**	**2**	**3**	**4**
Scoring Instruction	This would not make me think of the target at all	Minimal information is contained, such as the category	Several possible targets seem likely	One of two targets seem most likely	This directed me to the target
"What is a nest?"	"Eggs"	"Something birds have"	"a nest is where a bird goes in"	"what birds sleep in"	"birds make them when they are gonna have babies"

Table 3

Pearson's correlations between the five rate's scores for all children

	Rater 1	Rater 2	Rater 3	Rater 4	Rater 5
Rater 1	1.00				
Rater 2	.88*	1.00			
Rater 3	.88*	.95*	1.00		
Rater 4	.88*	.87*	.89*	1.00	
Rater 5	.88*	.94*	.96*	.86*	1.00

* = $p < .01$

Table 4

The SLI and CA groups' means and standard deviations (SD) for the definition scores for the four frequency categories, (1) high word frequency (WF), high neighborhood density (ND), (2) high WF, low ND, (3) low WF, high ND, (4) low WF, low ND and all words combined.

	High WF High ND	High WF Low ND	Low WF High ND	Low WF Low ND	All words combined
SLI					
Mean	2.43	2.41	2.25	2.42	2.38
SD	.59	.59	.53	.67	.56
CA					
Mean	3.05	3.05	2.84	3.01	3.01
SD	.42	.42	.33	.31	.31

Table 5

The SLI and CA groups' means and standard deviations (SD) for the three predictor variables inhibition, attention, and nonword repetition

	Inhibition	**Attention**	**Nonword Repetition**
SLI			
Mean	4.30	40.31	78.55
SD	.68	4.56	8.17
CA			
Mean	3.46	43.68	88.47
SD	.77	2.50	5.01

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Table 6

Pearson's correlations between children's Semantic Scores and the three predictor variables attention, inhibition and nonword repetition

Simple correlations				
	Semantic Score	*Inhibition*	*Attention*	*Nonword Repetition*
Semantic Score	1.00			
Inhibition	−.18	1.00		
Attention	.62*	.02	1.00	
Nonword Repetition	.41*	−.43*	.28	1.00
Partial correlations controlling for age				
	Semantic Score	*Inhibition*	*Attention*	*Nonword Repetition*
Semantic Score	1.00			
Inhibition	−.20	1.00		
Attention	.61*	−.03	1.00	
Nonword Repetition	.40*	−.43*	.13	1.00
Partial correlations controlling for CELF-3 Formulated Sentences subtest				
	Semantic Score	*Inhibition*	*Attention*	*Nonword Repetition*
Semantic Score	1.00			
Inhibition	.28	1.00		
Attention	.53*	.339	1.00	
Nonword Repetition	.20	−.16	.13	1.00

*=$p < .05$