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Research Article

Neighborhood Density and Syntactic Class Effects on Spoken Word Recognition: Specific Language Impairment and Typical Development

Jill R. Hoover[a]

Purpose: The purpose of the current study was to determine the effect of neighborhood density and syntactic class on word recognition in children with specific language impairment (SLI) and typical development (TD).
Method: Fifteen children with SLI (*M* age = 6;5 [years; months]) and 15 with TD (*M* age = 6;4) completed a forward gating task that presented consonant–vowel–consonant dense and sparse (neighborhood density) nouns and verbs (syntactic class).
Results: On all dependent variables, the SLI group performed like the TD group. Recognition performance was highest for dense words and nouns. The majority of 1st nontarget responses shared the 1st phoneme with the target (i.e., was in the target's cohort). When considering the ranking of word types from easiest to most difficult, children showed equivalent recognition performance for dense verbs and sparse nouns, which were both easier to recognize than sparse verbs but more difficult than dense nouns.
Conclusion: The current study yields new insight into how children access lexical–phonological information and syntactic class during the process of spoken word recognition. Given the identical pattern of results for the SLI and TD groups, we hypothesize that accessing lexical–phonological information may be a strength for children with SLI. We also discuss implications for using the forward gating paradigm as a measure of word recognition.

Specific language impairment (SLI), marked by difficulty with language expression and/or comprehension, is one of the most common forms of childhood language disorder (Bishop, 2010; Tomblin et al., 1997). Although the grammatical finiteness system (e.g., morphemes that mark verb tense and agreement) stands as a hallmark deficit area (Rice & Wexler, 1996; Rice, Wexler, & Cleave, 1995; Rice, Wexler, & Hershberger, 1998), the lexicon receives considerable attention as a second, common deficit area (e.g., Kan & Windsor, 2010). Unlike finiteness, however, the literature on lexical skills in SLI can yield a mixed picture in terms of pinpointing precise deficit areas. Clinically, this is important to resolve in order to improve both diagnostic and intervention techniques, especially given the important role of the lexicon in foundational academic skills like reading and writing (Catts, Fey, Tomblin, & Zhang, 2002). Given that lexical skills may lay a foundation for grammar/sentence construction, identifying areas of lexical strength/weakness could also lead to an improved understanding of grammatical finiteness marking in SLI (e.g., Bock & Levelt, 1994; McMurray, Samelson, Lee, & Tomblin, 2010). The purpose of this research was to examine spoken word recognition, a fundamental skill in producing and understanding spoken language, in children with SLI, with an emphasis on understanding how children dually access phonological and syntactic class information.

Lexical Skills in SLI

Learning new words can be challenging for children with SLI, especially during the preschool years (e.g., Kan & Windsor, 2010). The word-learning literature highlights a number of vulnerable aspects, including fast mapping (e.g., Alt & Plante, 2006; Rice, Buhr, & Nemeth, 1990), verb learning (e.g., Eyer et al., 2002), retaining newly learned words over time (e.g., Oetting, 1999), using argument structure to deduce meaning (e.g., Rice, Cleave, & Oetting, 2000), learning after minimal exposures (e.g., Rice, Oetting,

[a]Department of Communication Disorders, University of Massachusetts Amherst

Correspondence to Jill R. Hoover: jrhoover@comdis.umass.edu

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Marquis, Bode, & Pae, 1994), and adequately using cues that should facilitate learning (e.g., Gray, 2005). Spoken word recognition has also been identified as an area of difficulty. Here, the literature spans a wider age range, with effects often used to make hypotheses about the quality of underlying lexical representations (Dollaghan, 1998; Gray, Reiser, & Brinkley, 2012; Hennessey, Leitão, & Mucciarone, 2010; Mainela-Arnold, Evans, & Coady, 2008; McMurray et al., 2010; Montgomery, 1999; Rispens, Baker, & Duinmeijer, 2015). Many hypothesize that compromised quality of lexical representations, revealed through spoken word recognition paradigms, may be responsible for some of the word-learning deficits observed in SLI (Maillart, Schelstraete, & Hupet, 2004; Quémart & Maillart, 2016; Seiger-Gardner & Brooks, 2008). Spoken word recognition may provide critical insight into aspects of word knowledge needed to flexibly use words beyond simple recognition, like, for example, defining, using, and understanding words in sentences or comprehending text. Most theories of SLI identify sentence production and/or comprehension as a hallmark deficit area (e.g., Rice et al., 1995, 1998). Thus, studies aimed at assessing spoken word recognition in SLI could provide insight into basic language processing skills that critically underlie a core deficit area, in turn refining grammatical theories of SLI.

Spoken word recognition involves discriminating a word from a pool of candidates that is activated, and in competition, with a target but ultimately disregarded once a listener has sufficient information (e.g., Luce & McLennan, 2005). Many features affect word recognition, but phonological similarity has long been documented to influence discrimination (e.g., Marslen-Wilson, 1987). One common definition of phonological similarity considers words like *sick, click,* and *ick* to be neighbors of *kick* differing only by a single sound (Luce & Pisoni, 1998). Neighborhood density (ND), the quantification of phonological similarity, refers to a word's number of neighbors. One hypothesis about the lexicon is that words are organized into phonological neighborhoods where high ND words like *kick* reside in a dense neighborhood and low ND words like *move* reside in sparse neighborhoods. During recognition, a word's neighbors are activated and considered as possible targets. Depending on methodology, age, or clinical status, ND can either facilitate or hinder recognition (e.g., Garlock, Walley, & Metsala, 2001; Luce & Pisoni, 1998; Mainela-Arnold et al., 2008).

ND affects performance across a variety of language skills, making effects on language processing nearly ubiquitous (Vitevitch & Luce, 2016). The direction of effects (whether high or low ND facilitates recognition), however, is not static across the ages and is thought to reflect development of lexical representations (e.g., Metsala, 1997). As children learn new words, they store multiple pieces of information (e.g., phonological, semantic, syntactic) with the word's abstract, underlying lexical representation, and that information will be activated during recognition (e.g., Marslen-Wilson, 2007). ND is one piece of information thought to provide evidence of some of children's knowledge about the phonological component to the representation (e.g., Storkel & Morrisette, 2002). ND is also correlated with age of acquisition, such that dense words are earlier acquired than sparse words (Stokes, 2010; Storkel, 2004). Accordingly, the rate of change that lexical representations undergo is hypothesized to differ for dense versus sparse words. The lexical restructuring hypothesis is one developmental account of these differences that assumes that phonological word form representations are holistic early in development when the lexicon is relatively small (Garlock et al., 2001; Walley, 1993). Holistic representations are sufficient when the lexicon is small because fewer related words are activated and compete with the target, but lexical growth will eventually induce pressure for representations to become more detailed to facilitate discrimination. The shift from holistic to detailed should occur earlier for dense words because of the larger candidate pool competing for recognition (Walley, Metsala, & Garlock, 2003). As a result, phonological word form representations for dense words will initially be more robust than sparse. This has been experimentally validated via a dense word advantage on a number of experimental tasks (e.g., Hogan, 2010; Hoover, Storkel, & Rice, 2012; Sosa & Stoel-Gammon, 2012; Storkel, 2004). With documented difficulty in lexical skills for children with SLI, some hypothesize that phonological word form representations are at risk for undergoing this shift late or for the shift to be protracted and that this may be a contributing factor to lexical difficulty (Mainela-Arnold et al., 2008).

Lexical Representations in SLI

Word-learning studies have presented stimuli varying in ND (and phonotactics) to test hypotheses related to phonological word form representations under the assumption that weak representations may play a role in difficulties for children with SLI (e.g., Alt & Plante, 2006; Gray, Pittman, & Weinhold, 2014; Mckean, Letts, & Howard, 2014). The underlying premise was that differential performance between children with SLI and a control group might indicate representational deficits. The prediction was that either oversensitivity or undersensitivity to effects would reflect holistic phonological representations rather than more detailed representations expected for control groups. Children with SLI map fewer semantic features to novel word forms composed of phonotactically infrequent sounds (Alt & Plante, 2006). When phonotactics is orthogonally varied with ND, pinpointing group differences is more complex. McKean et al. (2014) tested whether faulty phonological representations, operationalized through ND and phonotactic effects, would lead to differences in the earliest phase (i.e., triggering) of word learning for children with SLI but found an identical pattern of effects in a control group. On the other hand, Gray et al. (2014) found group differences with respect to phonotactics and ND effects in the later phases of word learning (i.e., configuration).

Other word-learning studies have tested asynchronous learning between nouns and verbs (i.e., knowledge of syntactic class) as a way to speak to syntactic representations in children with SLI. Syntactic class determines how a word will be used in a sentence, including its corresponding inflectional morphemes. This is relevant for children with SLI given their pronounced difficulty with inflectional verb morphology (e.g., Rice et al., 1995). In fact, some hypothesize that verbs are difficult because the representation includes syntactic information, like tense and agreement. Difficulty with that information would likely impact storage and retrieval, which in turn, could impact sentence production (Andreu, Sanz-Torrent, & Guàrdia-Olmos, 2012; Hennessey et al., 2010). Importantly, not all aspects of verb learning are challenging for children with SLI. In fact, they perform like age-matched or language-matched controls on fast mapping (e.g., Eyer et al., 2002; Rice et al., 1990, 1994) and use of argument structure to deduce verb meaning (Oetting, 1999), but retaining and improving upon knowledge of newly learned verbs with time appear to be a weakness (Oetting, 1999; Rice et al., 1994). Moreover, Riches, Tomasello, and Conti-Ramsden (2005) demonstrated that verb learning for children with SLI might depend on a more carefully structured learning environment.

Taken together, there is evidence that knowledge encompassing phonological form and syntactic class may affect at least some aspects of word learning in SLI. Given multiple factors that may lead to word-learning vulnerability, it is important to plan studies that would allow us to determine how children simultaneously handle these multiple aspects of knowledge during lexical access. Additionally, the demands of word-learning paradigms may either overestimate or underestimate performance, thereby not providing the most accurate picture of phonological form or syntactic representations. Thus, evidence from spoken word recognition paradigms should also be considered to garner a complete understanding of the nature of lexical representations.

The forward gating paradigm has been used to understand the role of phonological word form representations in spoken word recognition, but results across studies have been mixed. The gating paradigm (Grosjean, 1996) is used to inform phonological representations because a listener's only cue is the acoustic–phonetic signal. Children hear a portion of the signal and are asked to guess the target. Although younger children with SLI recognize highly familiar nouns without difficulty (Dollaghan, 1998; Montgomery, 1999), they struggle with unfamiliar words compared to unimpaired controls. Moreover, the nontarget responses given during the gating task are less likely to come from the target word's phonological cohort or words that share the initial phoneme (e.g., "tie" would be a cohort response to "tooth"), a pattern not observed in unimpaired controls (Dollaghan, 1998). These latter two points of divergence are often taken as evidence that children with SLI may have difficulty accessing newly created lexical representations and properly narrowing the pool of candidates from which to select a target. Mainela-Arnold et al. (2008) presented words orthogonally varying in ND and word frequency in a gating task with older children (ages 8–12 years). Although they did not find group differences with respect to ND/word frequency, similar to Dollaghan (1998), they found that children with SLI generally had more difficulty settling on a target response. Mainela-Arnold et al. took this to mean that children with SLI may be more susceptible to competition effects. Given that these conclusions are drawn from gating studies, this is indication that at least some of their difficulty is along phonological grounds.

Syntactic class effects on spoken word recognition in SLI have also been documented, but to a lesser extent than phonological effects. With verbs as the foundation of sentences, it is possible that difficulty recognizing them may further complicate sentence construction for children with SLI. Moreover, the noun–verb disassociation in development may have consequences for other aspects of recognition, like how children simultaneously reconcile syntactic class and ND effects. Using the visual world paradigm, Andreu et al. (2012) examined recognition of nouns versus one-argument, two-argument, and three-argument verbs in children with SLI compared with age-matched and language-matched controls. All children showed a noun–verb disassociation (i.e., an advantage for nouns over verbs), but the age-matched control group outperformed both the SLI and language-matched control groups, who were not different from each other. Sheng and McGregor (2010) report a similar group effect for noun–verb naming. Lastly, verb, but not noun, repetition is negatively affected by concreteness for children with SLI, but not their age-matched controls (Hennessey et al., 2010). Taken together, noun–verb disassociations are apparent in spoken word recognition for all children (cf. Hennessey et al., 2010), but those with SLI appear impaired relative to age, but not language expectations. Thus, verb recognition might be best described as delayed in SLI.

Current Study

Our goal was to address a gap in the literature on what is known about simultaneous effects of phonological similarity (via ND effects) and syntactic class during childhood word recognition. We considered both because lexical representations are composed of multiple pieces of information (e.g., phonological, semantic, syntactic). We were particularly interested in whether our study could reveal new information about the extent to which phonological and/or syntactic levels of lexical representations may be compromised in children with SLI. With this in mind, we asked two research questions. First: How do phonological similarity and syntactic class affect performance during a forward gating task? Given dense–sparse and noun–verb disassociations in language processing, we hypothesized a ranking of recognition difficulty by orthogonal word type (i.e., dense nouns, dense verbs, sparse nouns, sparse verbs) that would reflect children's consideration of both pieces of information given auditory input via the gating paradigm. A result of this nature is consistent with adult models of spoken word recognition that suggest that a listener is able to determine multiple pieces of information (e.g., semantic, syntactic) about a lexical candidate given only phonetic input, like what the gating task delivers (e.g., Marslen-Wilson, 1987). Prior childhood word recognition studies have yet to test how syntactic class information might be activated in concert with phonological similarity, via ND effects. This design should reveal what lexical information children can determine via the gating task allowing us to garner a more accurate picture of the complex demands on recognizing spoken words.

Our second question was as follows: Do children with SLI show gating task performance indicative of compromised lexical representations at a phonological and/or syntactic class level? Here, we expected the same ranking of word type for children with SLI and typical development (TD) because the mere presence of dense–sparse and noun–verb disassociations appears to be unrelated to language impairment status. We hypothesized, however, that the morphosyntactic deficit in children with SLI would exacerbate the noun–verb dissociation because verbs carry syntactic information (e.g., Andreu et al., 2012; Hennessey et al., 2010; Kan & Windsor, 2010; Sheng & McGregor, 2010). This is consistent with hypotheses that limited verb representations, revealed through poor performance on lexical tasks, may be one of the problems underlying weak finiteness marking in children with SLI (e.g., Abel, Rice, & Bontempo, 2015; Hoover et al., 2012). Regardless of the outcomes, the results will help us understand how children simultaneously consider phonological and syntactic information during word recognition and whether isolated verb recognition emerges as an area of lexical difficulty in children with SLI. The latter will be important for improving predictions related to how the lexicon interfaces with syntax, thereby refining theories explaining why verb morphology is difficult for children with SLI (e.g., Rice et al., 1995).

Method

Participants

Thirty children participated, 15 with typical speech and language (TD group) and 15 with SLI (SLI group). All were recruited from the surrounding areas of Bloomington, Indiana, via flyers distributed in elementary schools and throughout the community and school language screenings. The TD group (seven male, eight female) ranged in age from 5;1 (years;months) to 7;8 (*M* age = 6;4) and the SLI group (11 male, four female) from 5;0 to 7;7 (*M* age = 6;5). The mean age of the TD and SLI groups did not differ, $t(28) = -0.503$, $p = .619$. All children completed standardized tests measuring receptive vocabulary (Peabody Picture Vocabulary Test–Fourth Edition; Dunn & Dunn, 2007), expressive vocabulary (Expressive Vocabulary Test–Second Edition; Williams, 2007), articulation (Goldman-Fristoe Test of Articulation–Second Edition; Goldman & Fristoe, 2000), language (Clinical Evaluation of Language Fundamentals–Fourth Edition [CELF-4]; Semel, Wiig, & Secord, 2003), expressive grammar (Test of Early Grammatical Impairment [TEGI]; Rice & Wexler, 2001), and nonverbal cognition (Leiter International Performance Scale–Revised; Roid & Miller, 1997). Inclusionary criteria for the study required all children to be monolingual English speakers and to demonstrate normal nonverbal cognition (Roid & Miller, 1997) and normal hearing (American Speech-Language-Hearing Association, 1997). To be included in the TD group, children were required to score within normal limits on all standardized measures listed above. The presence of SLI was verified by the following: (a) below age expectation criterion score on the screening portion of the TEGI (Rice & Wexler, 2001) and (b) a standard score at least 1 *SD* below the mean on the expressive, receptive, and/or core language indices of the CELF-4 (Semel et al., 2003). Children in the SLI group were not required to have a formal diagnosis of language impairment. The TD and SLI groups differed on the language measures used to diagnose SLI: the screening test of the TEGI, $t(28) = 3.271$, $p = .003$, the expressive language index, $t(27) = 9.046$, $p < .001$, and the core language index of the CELF-4, $t(27) = 8.921$, $p < .001$. Table 1 shows the participant characteristics.

Gating Task

We used the forward gating paradigm to measure the amount of acoustic–phonetic input required to recognize a word (Grosjean, 1996). Target words were presented successively in gates, or slices of the word, that increased in duration with each trial. Each successively presented gate was 60 ms longer than the previously presented gate. In our study, the duration of the first gate was 120 ms, the second gate was 180 ms (120 ms + 60 ms), the third gate was 240 ms (180 ms + 60 ms), and so forth. After each gate was played, participants were prompted to guess the word, and after each guess, another gate, 60 ms longer than the previous, was played.

Stimuli

Twenty-eight consonant–vowel–consonant (CVC) real words, orthogonally varying in ND (dense vs. sparse) and syntactic class (noun vs. verb) were selected and presented during the forward gating task. Half of the stimuli were dense ($n = 14$), and half were sparse ($n = 14$). Within the dense and sparse stimuli, half were nouns (seven dense and seven sparse nouns), and half were verbs (seven dense and seven sparse verbs). This selection yielded four conditions of stimuli: (a) dense nouns, (b) sparse nouns, (c) dense verbs, and (d) sparse verbs. ND values were obtained from an online interface that generates values on the basis of the Hoosier Mental Lexicon (Storkel & Hoover, 2010). Dense nouns (*M* = 24, range = 20–32) had more neighbors than sparse nouns (*M* = 9, range = 7–11), $t(12) = 8.21$, $p < .001$. Likewise, dense verbs (*M* = 25, range = 21–31) had more neighbors than sparse verbs (*M* = 9, range = 5–11),

Table 1. The means, standard deviations, and ranges of ages and standard scores on tests for children in the typically developing (TD) and specific language impairment (SLI) groups.

Group	Age (years;months)	PPVT-4[a]	EVT-2[b]	GFTA-2[c]	CELF-4[d] ELI	CELF-4[e] RLI	CELF-4[f] CLI	TEGI[g]	Leiter[h]
SLI									
M	6;5	99	101	83	78	89	80	66	96
SD	0;9	7	10	17	7	13	7	26	9
Range	5;0–7;7	89–112	89–125	60–111	65–89	65–105	64–88	6–92	85–109
TD									
M	6;4	112	108	105	109		109	90	108
SD	0;9	12	10	4	10	NA	10	10	14
Range	5;1–7;8	94–130	98–133	97–110	95–125		93–124	65–100	91–135

Note. PPVT-4 = Peabody Picture Vocabulary Test–Fourth Edition; EVT-2 = Expressive Vocabulary Test–Second Edition; GFTA-2 = Goldman-Fristoe Test of Articulation–Second Edition; CELF-4 = Clinical Evaluation of Language Fundamentals–Fourth Edition; ELI = Expressive Language Index; RLI = Receptive Language Index; CLI = Core Language Index; TEGI = Test of Early Grammatical Impairment; NA = not applicable.

[a]Standard scores from the Peabody Picture Vocabulary Test–Fourth Edition. [b]Standard scores from the Expressive Vocabulary Test–Second Edition. [c]Standard scores from the Goldman-Fristoe Test of Articulation–Second Edition. [d]Standard scores from the Clinical Evaluation of Language Fundamentals–Fourth Edition Expressive Language Index. [e]Standard scores from the Clinical Evaluation of Language Fundamentals–Fourth Edition Receptive Language Index. Children in the TD group did not complete the subtests needed to derive this index. [f]Standard scores from the Clinical Evaluation of Language Fundamentals–Fourth Edition Core Language Index. [g]Criterion score on the Test of Early Grammatical Impairment represents percentage correct of third person singular and regular past tense finiteness markers. [h]Standard scores from the Leiter International Performance Scale–Revised.

$t(12) = 11.72$, $p < .001$. In our manipulation of ND, we balanced other psycholinguistic variables (i.e., word frequency, phonotactic probability) allowing us to draw clearer conclusions given the sensitivity of ND to methodological nuances (Werker & Curtin, 2005). Word frequency, $t(12)$, = −0.096, $p = .925$, phonotactic probability of the first biphone, $t(12) = -0.241$, $p = .814$, and the average phonotactic probability of the entire word, $t(12) = -0.712$, $p = .50$, did not differ across the dense and sparse nouns. Likewise, dense and sparse verbs did not differ on word frequency, $t(12)$, = 0.858, $p = .407$, phonotactic probability of the first biphone, $t(26) = -0.402$, $p = .695$, and the average phonotactic probability of the entire word, $t(12) = 0.141$, $p = .89$. The Appendix shows the experimental stimuli and their characteristics.

Stimuli Preparation

A female native speaker of English with a midwestern dialect recorded the words in a soundproof booth while wearing a head-mounted microphone. Words were recorded at a 44.1-kHz sampling rate using Version 2.2.2 of Audacity recording and editing software (Audacity Team, 2010). The durations of dense (M = 558 ms, SD = 44 ms) and sparse words (M = 569 ms, SD = 37 ms) were similar, $t(26) = -0.737$, $p = .468$. We created the gated stimuli by clipping the words into gates starting at the beginning of the word, with 120 ms as the first gate and each subsequent gate 60 ms longer than the previous. Thus, for all words, the first gate was 120 ms, and those following were 180 ms, 240 ms, 300 ms, 360 ms, and so forth. Gates were created in this manner of adding 60 ms increments until the entire word duration was revealed. Thus, the last gate of every word was the duration of the entire CVC.

We presented the gated stimuli using the standard successive format (Walley, Michela, & Wood, 1995) because it allows the task to advance once the child correctly guesses the word. This reduces the overall length of the task, which was desirable given the age of participants. This format organizes the gates into a series for each word. Each series begins with the first gate (120 ms) and ends with the full word duration as the last gate. We inserted 4 s of silence after each gate to allow for response time. The series of gates were organized and presented via the iTunes program (Version 9.2.1) for Macintosh. We created two versions of lists where the order of target words was randomized. Children were randomly assigned to receive one of the lists. We played the stimuli over free-field desktop speakers connected to a Macintosh computer at a comfortable listening level.

Procedure

Children completed the standardized testing and gating task in two to three sessions in a quiet/private room. The first one or two sessions were devoted to standardized testing. Children completed the gating task during their final session. For the gating task, children were seated at a table directly in front of a tabletop microphone, which was used to record responses. The gating stimuli were played over desktop speakers that were positioned approximately 2 ft from the child. All children completed a brief pretraining to familiarize them with the gating task. The examiner read the following pretraining script to all children:

> We are going to play a word guessing game. In the word guessing game, you will listen to small pieces of words. At first, the pieces will be really tiny, but

> then they will get longer and longer. As soon as you hear something, you will tell me what word you think of. You will guess a word. The pieces will come really fast, so I want you to guess as soon as you hear something. Tell me your guess right away and say it loud so I can hear you. If you don't know what the word is, that's OK. Just tell me a word that you think of. It's OK to guess anything. You might even change your guess when you hear a longer piece of the word. That's OK too. Let's practice guessing some words.

The examiner then presented two CVC words (i.e., bus and doll) that were successively gated according to the procedures described above. Neither of these words was included in the experimental stimuli. After the child completed the pretraining, the examiner read the following script:

> Let's get ready to play the word guessing game. Remember, at first the word pieces will be really tiny, but then they will get longer and longer. Every time you hear something, tell me what word you think of. It's OK to make a guess if you don't know the word and it's OK to change your guess after you hear a longer piece of the word. Let's begin.

No children were excluded from the study for failing the pretraining. Children completed the gating task in 15 min.

Dependent Variables and Scoring

During the task, after each gate was played, the examiner wrote down the child's responses verbatim for later scoring. We used the responses to score for two dependent variables: (a) isolation point and (b) acceptance point. *Isolation point* was defined as the amount of acoustic–phonetic information (in milliseconds) that the child required to correctly identify the target word for the first time. For example, if the first time the child said the target word *game* was after hearing 180 ms, the isolation point would be recorded as 180 ms, even if the child gave a different response for later gates (e.g., saying "gate" after 240 ms). *Acceptance point,* on the other hand, was defined as the amount of acoustic–phonetic information (in milliseconds) that the child required to settle on the target word. Determining acceptance point required three consecutive responses, of which the first was recorded as the acceptance point. For example, if the child correctly guessed "game" after hearing 360, 420, and 480 ms of the target word "game," 360 ms (i.e., the first guess in the series of three) was recorded as the acceptance point. Once the acceptance point was established, the examiner advanced to a new trial or sequence of gates for a different target word. Following the procedures of Walley et al. (1995), both dependent variables for words that were never correctly recognized were recorded as the duration of the entire word + 60 ms (one additional gate). Inflected forms of words (e.g., plural versions of nouns or past tense versions of verbs) were scored as correct productions of the target words.

Reliability

A second judge independently scored both dependent variables for 20% of the data. For the TD group, isolation point agreement was 96%, and acceptance point agreement was 95%. For the SLI group, scoring agreement was 95% and, 94%, for isolation and acceptance points, respectively.

Results

We analyzed two dependent variables: (a) isolation point and (b) acceptance point using linear mixed-effects models (Baayen, Davidson, & Bates, 2008). In both models, subject and item were specified as random factors. To further understand potential interactions between ND and syntactic class that the mixed-effects model might not capture, we planned pairwise comparisons to determine the ranking of each word type (dense noun vs. dense verb vs. sparse noun vs. sparse verb) from the shortest to longest isolation and acceptance points. This allowed us to determine how children weight ND and syntactic class during the gating task. Table 2 presents the means and standard deviations for the isolation point and acceptance point–dependent variables for the four word types: dense nouns, sparse nouns, dense verbs, sparse verbs. Finally, to further examine group differences that would not be captured by isolation and acceptance points, we examined children's first nontarget responses.

Isolation Point

As described above, the isolation point is the amount of acoustic–phonetic information (measured in milliseconds) at which a child first produced the target word. The liner mixed-effects model included ND (dense vs. sparse), syntactic class (noun vs. verb), and group (TD vs. SLI) as fixed effects with subject and item included as random effects. The model revealed significant main effects of ND, $F(1, 803) = 49.001$, $p < .001$, and type, $F(1, 803) = 64.503$, $p < .001$, but the main effect of group was not significant, $F(1, 28) = 0.045$, $p = .834$. All children's first production of target dense ($M = 278$ ms; $SD = 37$ ms) words occurred earlier than target sparse ($M = 339$ ms; $SD = 39$ ms) words. Children's first production of target nouns ($M = 274$ ms; $SD = 41$ ms) was earlier than target verbs ($M = 343$ ms; $SD = 29$ ms). None of the interactions involving ND, type, or group were significant: all F values < 1.0; all p values > .3.

We were also interested in how the four word types (dense nouns, dense verbs, sparse nouns, and sparse verbs) ranked from shortest (requiring the least input to recognize) to longest (requiring the most input to recognize) isolation point. This allowed us to gain insight into "easiest" to "hardest" words for children to recognize during the gating task and to further determine the importance of either factor to recognition. We used paired-samples t tests to compare all word types to each other. This yielded six comparisons. We applied more stringent significance levels

Table 2. Means and standard deviations of word isolation and acceptance points in milliseconds.

Group	Target word isolation point in milliseconds				Target word acceptance point in milliseconds			
	Nouns		Verbs		Nouns		Verbs	
	Dense	Sparse	Dense	Sparse	Dense	Sparse	Dense	Sparse
SLI								
M	257	295	308	378	321	358	363	417
SD	(55)	(42)	(38)	(47)	(76)	(52)	(42)	(58)
TD								
M	237	304	309	378	293	340	355	393
SD	(45)	(54)	(50)	(34)	(56)	(34)	(41)	(36)

Note. SLI = specific language impairment; TD = typical development.

following the procedure of Holm's modification of Bonferroni to adjust for Type I error (Holm, 1979). Given that group did not interact with ND or syntactic class for isolation point, we analyzed the participant group data together. Ranked from shortest to longest isolation point was (a) dense nouns (M = 247 ms, SD = 50 ms), (b) sparse nouns (M = 300 ms, SD = 48 ms), (c) dense verbs (M = 309 ms, SD = 44 ms), and (d) sparse verbs (M = 378 ms, SD = 40 ms). Nearly every word type was significantly different from the others, all p values < .001, with the exception of sparse nouns, which were not different from dense verbs, p = .454.

Acceptance Point

The results from the analysis of acceptance point, the amount of acoustic–phonetic information required to settle on a target word, mirrored the isolation point. Using the same linear mixed-effects model to analyze the isolation point–dependent variable, we included ND (dense vs. sparse), syntactic class (noun vs. verb), and group (TD vs. SLI) as fixed effects with subject and item entered as random effects. The linear mixed-effects model revealed significant main effects of ND, $F(1, 802) = 22.581$, $p < .001$, and type, $F(1, 802) = 33.699$, $p < .001$, but not group, $F(1, 28) = 1.739$, $p = .198$. All children required less acoustic–phonetic information to settle on dense words (M = 333 ms; SD = 45) compared with sparse (M = 377 ms; SD = 43 ms) and nouns (M = 328 ms; SD = 51 ms) compared with verbs (M = 382 ms; SD = 37 ms). The interactions involving ND, type, or group were not significant: all F values < 2.0; all p values > .4.

The result also mirrored the isolation point in terms of ranking the four word types from shortest to longest acceptance point. Again, we used paired-samples t tests to compare all word conditions to each other adjusting for Type I error (Holm, 1979). Given that the group did not interact with ND or syntactic class, the participant group data were analyzed together. Ranked from shortest to longest acceptance point was (a) dense nouns (M = 307 ms, SD = 67 ms), (b) sparse nouns (M = 349 ms, SD = 44 ms), (c) dense verbs (M = 359 ms, SD = 41 ms), and (d) sparse verbs (M = 405 ms, SD = 49 ms). The pairwise comparison between sparse nouns and dense verbs was the only one that was not significant, p = .300. All other word types significantly differed from each other, all p values < .001.

First Nontarget Response Analysis

We considered the possibility that children's error responses could reveal differences between the SLI and TD groups that were not discoverable, measuring isolation point and acceptance point alone. Specifically, it is possible that the words children with SLI produce prior to settling on a target do not bear a relationship to the target word. This type of analysis should yield greater insight into some of the strategies children with SLI use when recognizing words. We referred to these error responses as "nontarget competitors" (NTCs). We analyzed the point at which children produced their first real-word NTC and compared this across groups. The point at which children produced their first real-word NTC did not differ across the TD (M = 143 ms, SD = 17 ms) and SLI groups (M = 144 ms, SD = 17 ms), $t(28) = .20$, $p = .844$. Next, we coded whether each NTC was (a) a cohort (shared same initial phoneme as target), (b) a phonological neighbor, or (c) unrelated to the target (neither a cohort nor a neighbor). The majority of all children's NTCs were cohorts of the target words (SLI group: M = .87, SD = .08; TD group: M = .89, SD = .08), and there was no difference between the proportion of these responses for the SLI and TD groups, $t(28) = -0.807$, $p = .426$. Children in the SLI and TD groups did not differ in terms of the proportion of their NTCs that were either neighbors of the targets, $t(28) = 1.14$, $p = .266$ or phonologically unrelated to the target, $t(28) = -0.58$, $p = .567$.

Results Summary

A consistent pattern of results emerged with respect to ND and syntactic class with the pattern of results for both groups converging in all respects. First, all children required less acoustic–phonetic information to correctly recognize dense, rather than sparse, words. Second, all required less information to recognize nouns compared with verbs. Third, in ranking the four word types, dense nouns had the shortest isolation and acceptance points, whereas sparse verbs had the longest. All children recognized dense verbs and sparse nouns similarly on the gating task. Finally, the majority of all children's first real-word NTCs were cohorts of the target.

Discussion

The goal of the current study was to determine how children harness lexical–phonological information, in concert with syntactic class, to aid word recognition. We asked two research questions: (a) How do phonological similarity and syntactic class affect performance during a forward gating task? and (b) Do children with SLI show gating task performance indicative of compromised lexical representations at a phonological and/or syntactic class level? Across the board, results converged for SLI and TD groups. The results from the current study have at least three important implications. First, they add to the broader understanding of lexical competition via exclusive ND effects in children. Second, the results provide insight into how children simultaneously weight lexical–phonological and syntactic representations during word recognition. Third, they improve our understanding of word recognition in children with SLI and allow us to consider whether word recognition can be used to inform grammatical theories of SLI (Rice et al., 1995).

Implications for Childhood Word Recognition

Our dense word advantage may appear at odds with the more commonly documented sparse advantage in the word recognition literature (e.g., Metsala, 1997). There is, however, one condition that triggers a dense advantage—when words are also low in frequency (e.g., Mainela-Arnold et al., 2008; Metsala, 1997). Because of the known ND–frequency interaction, we balanced frequency across dense and sparse words to garner a clearer picture of ND effects. This inadvertently led to a somewhat lower average frequency range than the high frequency range that triggers a sparse advantage. Metsala (1997) hypothesized that ND and frequency interact to afford differential processing advantages explaining the interaction as a byproduct of two distinct influences at play during word recognition: competition versus structural–residual effects. Structural–residual effects are most relevant to our data. During development, words that are either high in frequency or density facilitate performance as a result of earlier entrance into the lexicon (i.e., structural–residual effect). The phonological form of dense words is said to be more robust because similarity with many other words requires representing the form more segmentally to facilitate discrimination from other related forms (e.g., Storkel, 2002). Likewise, representations of high-frequency words are solidified through frequent exposure in the input. Competition effects, linked exclusively with ND, can interact with structural–residual effects with firmly represented high-frequency words triggering a sparse word recognition advantage. When presented with presumably weaker represented lower frequency words, however, the structural–residual effects take over, and a dense advantage is observed. Although we did not actively select low-frequency words, the mean frequency values of our dense and sparse words were lower than those of the high-frequency words used in both Metsala (1997) and Mainela-Arnold et al. (2008). This sheds further light on the ND–frequency interaction. There might be a frequency threshold that triggers the switch from a dense to sparse word advantage. This delicate interaction has been observed in phonology treatment for children where the direction of ND effects depended on whether frequency was balanced (Morrisette & Gierut, 2002) or orthogonally varied (Gierut & Morrisette, 2012). Future studies will need to tease apart the interaction to fully understand the developmental progression and how it interfaces with other statistical regularities that play a role in language processing.

The novel aspect of our gating study is that we orthogonally varied ND and syntactic class. Previous developmental gating studies have focused exclusively on documenting effects of form characteristics without attention to syntactic class. We, too, were interested in form characteristics, but given that a word's representation is composed of more than phonological structure, we also wanted to understand how syntactic class played into recognition. English-speaking children learn nouns before verbs (e.g., Gentner, 1982; Goldin-Meadow, Seligman, & Gelman, 1976). This is observed early with a toddler's vocabulary first primarily consisting of nouns, with the later addition of verbs (Nelson, 1973). When considering the syntactic representation of words, different pieces of information that dictate whether a word will be associated with a concrete object referent (i.e., nouns) or an action (i.e., verbs) will be learned. Verb-referent mapping is complex, and children must also learn syntactic features that will determine how the verb can be used in different sentences, for example. Thus, the current gating task was designed to trigger both children's phonological form and syntactic representations.

On the basis of Metsala's (1997) structural–residual definition and the noun–verb disassociation literature, we hypothesize that children will master the syntactic representation of nouns before verbs, thereby showing a noun advantage for the same reason that they show a dense advantage. Recall that we conducted pairwise comparisons to determine the ranking of our four word types. For both dependent variables, the word type with the shortest isolation/acceptance point was dense nouns with sparse verbs having the longest. Meanwhile, sparse nouns and dense verbs fell in the middle, with equal isolation/acceptance points. Note that the equal recognition of these two word conditions means that neither the expected noun–verb nor dense–sparse disassociation was observed. This finding supports one of our predictions that ND and syntactic class interact to yield an optimal condition pointing to both factors as equally important, rather than one emerging as most influential. Interestingly, the two conditions with equal isolation/acceptance points, sparse nouns and dense verbs, present conflicting information from a structural–residual perspective. Sparse nouns pair the optimal syntactic class with the less optimal ND condition, whereas dense verbs pair the optimal ND condition with the less optimal syntactic class. Thus, each condition features an element (either ND or syntactic class) that should be advantageous to the child, unlike dense nouns, which feature two advantageous elements or sparse verbs, which feature two disadvantageous elements. The novel finding from our study is that ND and syntactic class work in tandem to facilitate (or hinder) word recognition. In other words, ND and syntactic class afford a similar type of differential processing advantage that Metsala (1997) noted for ND and frequency. This finding supports recognition models assuming multiple pieces of information about a word's representation are active during discrimination (e.g., Marslen-Wilson, 2007).

Implications for SLI

We did not find evidence that children with SLI have weaknesses with phonological or syntactic representations. In all ways, the SLI group mirrored the TD group. We interpret this as providing insight into potential areas of strength for SLI but also motivation for future studies that might be better suited toward identifying areas of lexical vulnerability. Successful word recognition in our study required children to dually rely on phonological and syntactic class information. Our prediction that children with SLI would show a pattern of ND effects like typical peers was supported. This is consistent with previous gating studies in older children (Mainela-Arnold et al., 2008). Our novel contribution is that we were able to demonstrate an ND effect for gating in young children with SLI suggesting that words are already organized into phonological similarity neighborhoods by 6 years, like we expect in TD. Whereas previous studies have hypothesized that the ability to accurately suppress neighbor competitors may be problematic, our results did not support that (e.g., Dollaghan, 1998; Mainela-Arnold et al., 2008). It is important to note, however, that phonological form representations via ND effects are not the only way to gather insight into this level of representation and that gating is not the only method of assessment. Methodological extensions will be needed to fully inform the status of this level of representation in children with SLI.

Our ND effects confirm Mainela-Arnold et al.'s (2008) conclusion that lexical–phonological representations are intact for SLI, but the overall task performance result is at odds. Mainela-Arnold et al. reported later acceptance points for the SLI group indicating difficulty settling on the target. Children with SLI also produced a slightly higher proportion of NTCs that were unrelated to the target. Both of these results point to some level of deficit. In our gating task, the main effect of group was not significant, and there were no differences with respect to NTCs. One possible reason for this discrepancy is language severity. On average, the children in our SLI group had noticeably higher standard scores on the receptive language index of the Clinical Evaluation of Language Fundamentals and the Expressive Vocabulary Test. These differences might have impacted the main effect of group, suggesting that word recognition deficits may be associated with severity of impairment. Another explanation is that lexical–phonological deficits emerge with age. The children in Mainela-Arnold et al. (2008) were, on average, more than 3 years older than the children in our study. McMurray et al. (2010) reported that adolescents with SLI have difficulty suppressing phonological competitors using the visual world paradigm, whereas Montgomery (1999) and Dollaghan (1998) both reported no difference in recognizing familiar words on a gating task for children in a similar age range as our SLI group. This claim would best be validated through a longitudinal study documenting the time course of word recognition in SLI. A third explanation is a difference in format used to deliver the gated stimuli. Mainela-Arnold et al. (2008) used the blocked format while we used the successive. The successive format provides small clips of one word until an acceptance point is established, after which the child moves on to the next word. The blocked format presents the 120-ms clips of all target words, followed by the 180-ms clips, and so on. With the blocked format, the child is presumably activating a new pool of candidate words on each trial. The successive format keeps one pool active until an acceptance point is established and moves onto the next. Both formats are valid measures of recognition (Walley et al., 1995), but this difference has consequences for the pool of candidates activated. Future studies will need to test ND and syntactic class effects using a blocked format to determine the impact this has on recognition.

In terms of syntactic class effects, we predicted children with SLI to show a disproportionate difficulty with verbs. In fact, we expected our design to shed light on the mixed findings related to whether phonological word form representations are weak in SLI given that previous studies had not considered syntactic class (e.g., Dollaghan, 1998; Montgomery, 1999). This was important because children with SLI are reported to show noun–verb dissociations indicative of an earlier stage in development (Sheng & McGregor, 2010) and exacerbated verb-learning deficits (Eyer et al., 2002). Surprisingly, children with SLI did not demonstrate any more difficulty with verbs than children in the control group. In fact, Table 2 shows the difference between noun and verb recognition to be identical for the groups. Given that verb recognition was identical across groups, our results do not provide evidence that would allow us to hypothesize the grammatical deficit in SLI to be somehow traced back to difficulty recognizing verbs given only phonological input. It is important to point out, however, that previous studies demonstrating verb deficits in children with SLI used paradigms that require children to activate semantic information associated with lexical representations, like for example, picture naming and fast mapping, both of which require a child to produce, or learn, a word form and associate it with a picture referent (e.g., Eyer et al., 2002; Sheng & McGregor, 2010). Paradigms that include picture referents presumably trigger an attempt to access semantic information. In fact, Rispens et al.

(2015), who documented ND differences between SLI and age-matched controls on a paired picture lexical decision task, partially attributed the finding to their task triggering lexical semantic information in a way that a gating task would not. Moreover, Gray (2005) showed that word learning in SLI can be facilitated by phonological, but not semantic, cues, further supporting the notion that the lexical semantic, rather than lexical–phonological level may be impaired. It would be valuable for future studies to consider syntactic class in tasks that emphasize verb meaning, rather than form only.

Besides the fact that gating heavily taps a phonological rather than semantic level, there is at least one additional reason that the task might not uncover vulnerabilities in SLI. The gating task does not reflect how we naturally encounter words. In everyday language, whole words are recognized as part of running speech. The repetition that is inherent to the successive format of gating might be overly advantageous for children with SLI. Previous research has shown that children with SLI can learn words comparably to control groups given more exposure (e.g., Gray, 2003; Rice et al., 1994). The gating task essentially does just that. It provides repeated information regarding a word's onset presumably spotlighting the pool of lexical candidates that the child should consider for recognition. This spotlighting is not something that the child would normally have access to in running speech. Thus, a logical next step is to consider tasks more representative of natural speech, which could conceivably be more challenging for children with SLI and yield a truer picture of word recognition ability.

Conclusions

This study provides new insights into childhood word recognition, both in TD and SLI. First, we were able to isolate ND effects and replicate the structural–residual effects that Metsala (1997) predicted for dense words. This finding motivates continued inquiry that could yield more precise insight into how neighborhood structure interfaces with frequency to facilitate or hinder recognition. Second, the findings provide new information on how ND interfaces with syntactic class. We were able to demonstrate that both phonological and syntactic information are active during the gating task. This was demonstrated by the ranking of word types with dense nouns affording the greatest recognition advantage and sparse verbs posing the greatest challenge. The relevance of syntactic class to the gating task is a particularly novel finding given that the nature of gating is heavily phonological. Even in a task that presents the listener with only a portion of the auditory signal, syntactic class emerged as relevant. This supports theories of word recognition that assume that multiple levels of representation are simultaneously active during discrimination (e.g., Marslen-Wilson, 2007). We also demonstrated that the two word types that present conflicting information (i.e., dense verbs and sparse nouns) from a structural–residual standpoint, show similar recognition patterns. This finding has implications for future studies that aim to uncover basic information about word processing that might eventually be used to motivate treatment studies in the area of vocabulary or grammar/sentence production for children with SLI. Specifically, if future studies could identify other conditions under which dense nouns afford word recognition advantages, one might be able to design studies that would test the utility of selecting these words as intervention targets to determine whether learning can be facilitated in the context of treatment. Finally, our results provide insight into how children with SLI compare to age-matched controls. Children with SLI show noun–verb recognition patterns that mirror age-matched controls on a task that primarily requires accessing lexical–phonological information. Although we suggest that this might be a relative strength for SLI, we point out ways in which the gating paradigm could artificially boost performance. Given this, it will be critical for future studies to incorporate additional methodologies that would allow us to come closer to understanding strengths and weaknesses for lexical skills for children with SLI, which, in turn, may be used to motivate new lines of inquiry advancing theories of language impairment in SLI.

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Appendix

Experimental Stimuli

Variables	Dense words: Nouns	Dense words: Verbs	Sparse words: Nouns	Sparse words: Verbs
	Game	Peek	Foot	Search
	Bird	Talk	Web	Fetch
	Top	Hurt	Nurse	Pour
	Ball	Shake	Song	Push
	Nail	Keep	House	Give
	Boot	Wait	Peg	Join
	Sheep	Fall	Voice	Move
Density				
M	24	25	9	8
Range	20–32	21–31	7–11	5–11
Segment average				
M	0.0403	0.0438	0.0432	0.0432
Range	0.0262–0.0474	0.0308–0.0566	0.0349–0.0584	0.0341–0.0598
First biphone				
M	0.0014	0.0012	0.0015	0.0014
Range	0.0008–0.0022	0.0006–0.0023	0.0004–0.0045	0.0004–0.0035
Log word frequency				
M	2.6	2.87	2.63	2.54
Range	1.78–3.31	2.23–3.42	1.6–3.77	1–3.59