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Rapid Naming by Children With and Without Specific Language Impairment

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Abstract

Purpose—Previous studies have reported that children with specific language impairment (SLI) name pictures more slowly than do chronological age-matched (CAM) peers. Rapid naming depends on 2 factors known to be problematic for children with SLI—lexical retrieval and nonlinguistic speed of processing. Although all studies implicate a speed-of-processing deficit as a contributing factor, researchers do not agree on the influence of language factors. The purpose of the current study was to explore word frequency (WF) and phonotactic pattern frequency (PPF) as potential lexical factors contributing to the naming deficits experienced by children with SLI.

Method—Three groups of children—20 children with SLI ($M_{\text{age}} = 9;8$ [years;months]), 20 younger vocabulary-matched (VM) controls, and 20 CAM controls—named pictures whose labels varied by WF and PPF.

Results—Reaction time results revealed significant main effects of group (CAM < SLI = VM) and WF (high WF < low WF). Effects due to WF were comparable for all groups, but a significant Group $\times$ PPF interaction revealed that PPF effects were greater for children with SLI than for VM or CAM children.

Conclusion—Results replicate previous findings of a naming deficit in children with SLI. Furthermore, results suggest that children with SLI are more vulnerable to increased competition from words with frequent phonotactic patterns, which also come from dense phonological neighborhoods.

Keywords

specific language impairment; rapid naming; lexical retrieval; word frequency; phonotactic pattern frequency

Children with specific language impairment (SLI) experience a variety of well-documented lexical deficits. Retrospective studies indicate that children with SLI acquire their first words later than do their typically developing peers (see, e.g., Trauner, Wulfeck, Tallal, & Hesselink, 2000). They tend to learn words more slowly (Alt & Plante, 2006; Dollaghan, 1987; Gray, 2004, 2005, 2006; Leonard et al., 1982; Rice, Buhr, & Oetting, 1992; Rice, Oetting, Marquis, Bode, & Pae, 1994) and to be more vulnerable to factors that complicate

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input (Ellis Weismer & Hesketh, 1993, 1996; Horohov & Oetting, 2004). For words that they already know, children with SLI exhibit lexical deficits in a variety of tasks. In gating tasks, they identify familiar words with as little acoustic information as do their chronological age-matched controls, but they need more acoustic information to identify less frequent words (Dollaghan, 1998; Mainela-Arnold, Evans, & Coady, 2008; Montgomery, 1999). They are slower to recognize words than are age-matched typically developing children (Edwards & Lahey, 1996). Furthermore, their performance in definition and drawing tasks suggests that their semantic representations of known words are less robustly specified (Mainela-Arnold, Evans, & Coady, 2010b; Marinellie & Johnson, 2002; McGregor & Appel, 2002; McGregor, Newman, Reilly, & Capone, 2002). Together, these findings suggest that children with SLI have small vocabularies at any point in development, difficulty adding new words to their lexicons, and inefficient access to words that they do know.

Another piece of evidence supporting a lexical deficit is the finding that children with SLI tend to name pictures more slowly and less accurately than do their typically developing peers. This naming deficit holds even though these children can comprehend the same words, as measured by a picture-pointing task. Kail and Leonard (1986) identified a study by Anderson (1965) as the first to show that children with language impairments name line drawings of familiar objects more slowly than do age-matched typically developing peers, a finding subsequently replicated by other researchers (Fried-Oken, 1984; Rubin & Liberman, 1983; Wiig, Semel, & Nystrom, 1982).

Our current understanding is that rapid naming is supported by two component processes—phonological processing and speed of processing (see, e.g., Denckla & Cutting, 1999). The phonological processing component is evidenced by effects that are due to age and effects that are due to word frequency. First, the time required to name pictures decreases as a function of age (Denckla & Rudel, 1974; Milianti & Cullinan, 1974). Second, pictures whose labels occur frequently in the language environment are named more quickly than pictures representing infrequent words (Oldfield & Wingfield, 1964, 1965). Both of these effects presumably result from the strength of underlying lexical representations. Younger children likely have less robustly specified lexical representations than do older children (see, e.g., Metsala & Walley, 1998); thus, their words are characterized by fewer and weaker semantic and phonological associations. In a similar way, frequently occurring words will be more familiar and thus will have a greater number of stronger semantic and phonological associations. Evidence for the speed-of-processing component in picture naming comes from studies looking at rapid naming by children with dyslexia. In these studies, rapid naming contributed unique variance to reading measures over and above variance due to phonological awareness measures (Denckla & Cutting, 1999; Wolf, 1997).

Researchers have considered both nonlinguistic and linguistic factors in discussions of naming deficits in children with SLI (Kail & Leonard, 1986; Lahey & Edwards, 1996; Leonard, Nippold, Kail, & Hale, 1983). All of these naming studies have reported that at least part of the naming deficit can be attributed to slower speed of processing. A typical finding comes from the Edwards and Lahey study (1996), in which children with SLI processed visual information as quickly as did their unimpaired peers but took longer to

respond in both visual and auditory conditions. Children were instructed to say “yes” when they saw a circle in one condition or heard a tone in another. Children with SLI were slower to respond overall but showed the same pattern as typically developing children of responding more slowly to visual versus auditory stimuli. These findings are consistent with a number of other studies whose authors argued that at least one factor contributing to the overall impairment in this population of children is a generalized slowing affecting all domains, linguistic and nonlinguistic (Kail, 1994; Leonard et al., 2007; Miller, Kail, Leonard, & Tomblin, 2001; Windsor & Hwang, 1999).

Although results consistently implicate processing speed as a contributing factor, there is no consensus as to the degree to which linguistic factors affect picture naming in children with SLI. Leonard and colleagues (1983) asked children to name pictures whose labels varied in word frequency (WF). They reported significant main effects of group and WF, but nonsignificant interactions revealed that all groups were similarly affected by WF. Kail and Leonard (1986) asked children to name pictures after a random list of words (no linguistic context), after a single sentence in which the picture to be named represented the last missing word in the sentence (sparse linguistic context), or after several sentences in the context of a meaningful story (rich linguistic context). Kail and Leonard found significant main effects of group and condition, in which naming times for all children improved with richer language context. However, the Group $\times$ Condition interaction was not significant, suggesting that children with SLI and age-matched controls received comparable facilitation from language context. Lahey and Edwards (1996) asked children to name pictures after a variable delay. That is, children had to inhibit their response until they heard a tone presented up to 1,200 ms after the picture appeared. In no-delay conditions, naming times reflect the combined effects of lexical retrieval and naming. As the delay interval increases, response times should decrease because the beginning portion of the process of lexical retrieval can occur before a response is required. The *point of asymptote* (POA), or the time point at which response times no longer decrease, should then reflect the time required for lexical access. Using this method, Lahey and Edwards reported that children with SLI were slower overall than age-matched peers, but they were similarly affected by increasing delay intervals, with a similar POA. Although these findings seem to suggest that group differences in picture naming cannot be attributed to linguistic causes, there is evidence that lexical retrieval is impaired in this population.

Kail and Leonard (1986) reported results of a task in which children saw pairs of pictures and determined whether (a) the pairs were physically the same or different and (b) whether their labels were the same or different. Some pairs were physically identical and thus had the same label. Other pairs were physically different but shared the same label (e.g., “peeled” vs. “banana”). Still others were physically different with different labels (e.g., “apple” vs. “banana”). Children were first asked whether two pictures were physically identical, a question whose response does not require lexical retrieval. In this condition, children with SLI were slower to make these judgments, suggesting slower perceptual–motor processing. In the second condition, children were asked whether objects’ labels were the same, a question whose response does require lexical retrieval. In this condition, children with SLI were again slower. For pictures with the same label, children with SLI were slower for both physically identical and physically different cases. However, group differences were greater

for physically different instances. This pattern of results implicates both nonlinguistic and linguistic factors in the naming deficit.

Two lexical/linguistic factors that have been explored a great deal recently are *word frequency* (WF) and *phonotactic pattern frequency* (PPF). WF, or how often a particular word occurs in the language environment, is known to affect the speed and accuracy with which individual words are accessed, retrieved, and selected (see, e.g., Balota & Chumbley, 1984; Luce & Pisoni, 1998). Further, children with SLI show the same WF effects as typically developing controls, responding more quickly and accurately to high-WF words versus low-WF words. For example, Leonard et al.'s (1983) picture-naming study reported that children with SLI showed slower or less accurate lexical processing but showed the same effects—due to WF—as typically developing children. This pattern also was reported for a gating task (Mainela-Arnold et al., 2008), in which a listener hears small acoustic chunks of spoken words. The acoustic chunks start out small but become progressively larger over successive trials, and listeners try to guess words' identities after hearing each chunk (Grosjean, 1980). Similar findings were reported from memory tasks, both for list recall (Coady, Mainela-Arnold, & Evans, 2013) and for a dualprocessing verbal working memory task in which children hear a list of sentences, judge their veracity, and then recall the sentences' final words (Mainela-Arnold et al., 2010a). Norbury, Bishop, and Briscoe (1999) also reported group differences but a similar WF effect in a past-tense elicitation study.

Another language factor known to affect lexical processing is the frequency of a word's phonological patterns, or *phonotactic pattern frequency* (PPF). Traditionally, effects due to PPF have been separated into phonotactic probability (PP) effects and neighborhood density (ND) effects. *PPF* is a blanket term that encompasses both PP and ND. It is meant to represent the frequency with which words' phonological patterns occur in the language environment. As such, it is not a novel construct but instead acknowledges that PP and ND are two different surface measures of the same underlying construct.

PP refers to the frequency with which a word's constituent phonemes occur and co-occur in the language environment. PP effects are typically facilitatory, such that performance is quicker and more accurate for items with frequently occurring sound patterns. An example of such a task is the *nonword repetition task* (NWR), in which a listener hears a nonword and then immediately repeats it. A consistent finding from NWR tasks is that nonwords with frequently occurring phonotactic patterns are repeated more accurately than are those with infrequent phonotactic patterns (Coady & Aslin, 2004; Coady, Evans, & Kluender, 2010a; Munson, Kurtz, & Windsor, 2005; Zamuner, 2009; Zamuner, Gerken, & Hammond, 2004).

ND refers to the number and frequency of words that share considerable phonemic overlap with a target word (Luce & Pisoni, 1998). For example, the word *cat* is phonemically similar to more than 25 other words, including *sat*, *that*, *cut*, *caught*, *can*, and *catch*. The word *dog*, on the other hand, has fewer than 10 neighbors, including *fog*, *log*, *dig*, *dug*, *dawn*, and *door*. Furthermore, the neighbors of *cat* occur very frequently, with more than 17,000 occurrences per million words, whereas the neighbors of *dog* occur less frequently, with fewer than 500 occurrences per million words. These two factors—the number and frequency of similar-

sounding neighbors—are meant to provide an index of lexical competition. ND effects are typically inhibitory, with listeners displaying slower and less accurate processing of words with many neighbors. An example of such an inhibitory effect comes from gating studies. As mentioned above, listeners identify frequently occurring words with less acoustic information than they need for infrequent words (Grosjean, 1980). However, listeners need more acoustic information to identify words with high ND compared with words with low ND (Mainela-Arnold et al., 2008; Metsala, 1997). These effects presumably arise because words with many neighbors or high-frequency neighbors are subject to increased competition from the greater number of similar-sounding words. A notable characteristic of these ND effects is that they interact with WF (Mainela-Arnold et al., 2008; Metsala, 1997). Examination of these interactions—at least, in gating studies—reveals that ND exerts an inhibitory effect for high-WF words but a facilitatory effect for low-WF words, much like the PP effects for nonwords.

PP and ND are related theoretically in that words that sound like many other words (with high ND) have high-frequency phonotactic patterns, and vice versa. Even so, researchers have maintained a distinction between them for a number of reasons (Vitevitch & Luce, 1998, 1999; Vitevitch, Luce, Pisoni, & Auer, 1999). One reason is the difference in the directionality of the effects. PP exerts a facilitatory effect, whereas ND exerts an inhibitory effect. Another difference is the hypothesized source of the effects. PP effects are related to the frequency of occurrence of phonemes or phoneme combinations, and so these effects are assumed to be phonological, or sublexical. ND effects are related to competition from similar-sounding whole words, and so those effects are assumed to be at the word level, or lexical. Finally, PP and ND operate on different types of stimuli, with PP effects dominating in the processing of nonwords and ND effects dominating in the processing of real words. More recent findings, however, suggest that this distinction between PP and ND effects is not so clear-cut. Vitevitch and Luce (1999) reported that tasks can be manipulated to enhance nondominant effects in the processing of both words and nonwords. That is, listeners can and do show inhibitory, lexical-level effects in the processing of nonwords (Storkel, Armbruster, & Hogan, 2006; Storkel & Hoover, 2010) as well as facilitatory, sublexical-level effects in the processing of real words (Roodenrys, Hulme, Lethbridge, Hinton, & Nimmo, 2002; Yates, Friend, & Ploetz, 2008).

PP and ND are now ubiquitous factors in studies examining lexical processes in typical adults and children. In recent studies, researchers also have begun to examine whether children with SLI are subject to these same lexical and sublexical effects and, if so, whether these effects are comparable to those for typically developing peers. For facilitatory sublexical PP effects, results suggest that children with SLI tend to be slower or less accurate, but the magnitude of facilitation due to PP is similar to that for typically developing controls. In one study, Coady and colleagues (2010a) reported that children with SLI repeated nonwords varying in PP less accurately than did age-matched peers but showed comparable facilitation due to PP. In another study, Coady, Evans, and Kluender (2010b) found that children with SLI repeated consonant–vowel–consonant (CVC) target words embedded in meaningful sentences less accurately than did their age-matched peers. However, all children repeated high-PPF CVC words more accurately than they did low-PPF words, and the magnitude of this effect was similar for both groups. Presumably, facilitatory

effects were made possible by meaningful semantic contexts that reduced competition. There are exceptions to this pattern, including nonword repetition tasks in which PP differences between nonwords are maximized (Coady, 2010; Munson et al., 2005) and a verbal recall task using a large number of lists of real words differing in PPF (Coady et al., 2013). In these cases, typically developing children show increased performance for high- versus low-PPF items, but children with SLI show either reduced facilitation, or no facilitation at all. Other than these exceptions, nonsignificant Group $\times$ PP interactions suggest that children with SLI are extracting and using phonological regularities in a manner comparable to that of age-matched, typically developing peers.

For inhibitory lexical-level ND effects, results suggest that children with SLI are more vulnerable to competition from structurally similar words. In their gating task, Mainela-Arnold and colleagues (2008) included words that differed in WF and ND. They reported that the magnitude of WF and ND effects and the magnitude of the Frequency $\times$ Density interaction were comparable for children with SLI and for age-matched, typically developing peers. However, the pattern of results suggested that children with SLI were more vulnerable to competition. Groups did not differ in the gate at which they identified a word starting with the same initial phoneme as that of the target word, nor did they differ in the gate at which they first correctly identified the target. However, children with SLI were more likely to change their guess after successfully identifying the correct word. This difference in the point of acceptance suggests that children with SLI keep cohort competitors active for a longer period of time. Newman and German (2002) also examined ND effects in children with word-finding difficulties for picture-naming and sentence-completion tasks. They did not directly compare groups, but they did report that effect sizes were larger for children with word-finding difficulties. Although not definitive, these results suggest that children with SLI exhibit larger inhibitory, lexical effects than do age-matched peers.

The current study examined the degree to which the lexical factors of WF and PPF affect the speed with which children with SLI name pictures. Children with SLI were compared with two groups of children with typical language development—one group that was matched in chronological age and a second, younger group that was matched in vocabulary. The specific questions that the current study sought to answer were as follows: (a) Are there any differences in the accuracy or speed at which children with SLI, age-matched controls, and vocabulary-matched controls name pictures? and (b) Is picture naming by children with SLI, age-matched controls, and vocabulary-matched controls affected by manipulations of WF and/or PPF in the same way?

Because rapid picture naming depends on phonological processing, children with SLI are hypothesized to be slower than age-matched controls. However, because rapid picture naming also depends on speed of processing, children with SLI are hypothesized to be faster than vocabulary-matched controls. On the basis of previous findings, children with SLI are hypothesized to be similarly affected by WF, but more affected by PPF, in a picture-naming task in which the frequency of words' phonological patterns typically exerts an inhibitory effect. This pattern of results would support the claim that children with SLI are more vulnerable to competition from structurally similar words, a finding not yet demonstrated directly.

Method

Participants

Sixty monolingual English-speaking children, composing three groups, participated. The first group included 20 children with SLI: nine girls and 11 boys ($M_{\text{age}} = 9;8$ [years; months]; range = 7;7–13;4). The second group included 20 typically developing children matched on chronological age: 10 girls and 10 boys ($M_{\text{age}} = 9;7$; range = 7;2–12;10). The third group included 20 younger typically developing children matched on expressive vocabulary scores: 10 females and 10 males ($M_{\text{age}} = 6;8$; range = 5;9–8;1). Both control groups were matched to the group of children with SLI on the basis of group mean scores. There was no significant age difference between children with SLI and chronological age-matched (CAM) children, $t(38) = 0.13$, $p = .90$, but children with SLI were significantly older than vocabulary-matched (VM) children, $t(38) = 7.98$, $p < .0001$. Children were drawn from a larger sample of children in local schools. Children with SLI were referred because they were receiving services from school speech-language pathologists. Those children met exclusion criteria (Leonard, 1998), having no frank neurological impairments, no evidence of oral-motor disabilities, normal hearing sensitivity, and no social or emotional difficulties based on parent report. It was important to ensure that any potential group differences in picture naming can be attributed to language status rather than overall intelligence; thus, all children had nonverbal IQs above 85 (> 1 SD below the mean) as measured by the Leiter International Performance Scale—Revised (Leiter-R; Roid & Miller, 1997). Summary statistics are provided in Table 1. There were no significant nonverbal IQ differences between children with SLI (range = 87–119) and CAM controls (range = 87–107), $t(38) = 0.75$, $p = .46$, but children with SLI had standard scores significantly below those of VM children (range = 100–124), $t(38) = 5.80$, $p < .0001$. Although the group mean for children with SLI was lower than that for VM children, it is important to note that all children scored within normal limits (> 87). To control for possible confounding effects of articulation impairments, we included only those children without articulation deficits. Speech intelligibility during spontaneous production was at or above 98% for all children, as measured during conversational interaction by a certified speech-language pathologist. All children also had normal-range hearing sensitivity on the day of testing as indexed by audiometric pure-tone screening at 25 dB for 500-Hz tones and at 20 dB for 1000-, 2000-, and 4000-Hz tones. Finally, there was a significant difference in maternal education among the three groups, with lower levels of maternal education for the children with SLI relative to both control groups, $F(2, 52) = 7.66$, $p < .001$. This pattern suggests reduced language input to children with SLI (Hart & Risley, 1995; Hoff, 2003), which might compromise language acquisition. Accordingly, the degree to which maternal education affected the naming results was explored by covarying this variable out of statistical analysis.

The language matching was based on raw scores from the Expressive Vocabulary Test (EVT; Williams, 1997). Expressive vocabulary was chosen because it is the most similar to the picture-naming task, with both tasks asking children to generate labels of known objects. The mean EVT raw score for children with SLI was 74.7, and the mean for the VM group was 73.4. This difference was not significant, $F(1, 38) = 0.181$, $p = .673$, $\eta^2_p = .005$. However, the groups did differ on standard scores: 83.8 and 107.8, respectively, $F(1, 38) =$

84.39, $p < .001$, $\eta^2_p = .690$. In this and subsequent analyses, effect size in the form of η^2_p is reported. *Partial eta squared*, or η^2_p , is the proportion of variance explained by the effect in question, after other variables have been partialled out. Although effect sizes are relative both to other effect sizes and to the particular area of investigation, generally, .01 is considered a small effect, .09 is considered a medium effect, and .25 is considered a large effect.

The language assessment measure was the Clinical Evaluation of Language Fundamentals—Third Edition (CELF–3; Semel, Wiig, & Secord, 1995). Children with SLI received the full expressive and receptive language batteries of the CELF–3, and composite expressive language scores (ELs) and composite receptive language scores (RLs) were calculated. Typically developing children received the full expressive language battery of the CELF–3, and their receptive language was screened with the Concepts and Directions subtest of the receptive language battery. Children with SLI scored below 85, or at least 1 *SD* below the mean on both the EL and RL, whereas typically developing children obtained a score above 85 on the EL, and a standard score of 7 or above on the Concepts and Directions subtest. Receptive and expressive vocabulary measures were the Peabody Picture Vocabulary Test—Third Edition (PPVT–III; Dunn & Dunn, 1997) and the EVT (Williams, 1997), respectively. Two additional language measures were collected but not used for diagnosis: The NWR (Dollaghan & Campbell, 1998) was collected as a descriptive measure of phonological working memory, and the Competing Language Processing Task (CLPT; Gaulin & Campbell, 1994) was collected as a descriptive measure of verbal working memory. Group means for standardized and working memory measures are provided in Table 1.

Children with SLI scored significantly lower than both CAM and VM children on standard expressive language scores from the CELF: SLI versus CAM, $F(1, 38) = 104.024$, $p < .0001$, $\eta^2_p = .732$; SLI versus VM, $F(1, 38) = 117.258$, $p < .0001$, $\eta^2_p = .755$. They also scored lower than both groups on the receptive language screener from the CELF; the Concepts and Directions subtest; SLI versus CAM, $F(1, 38) = 42.432$, $p < .0001$, $\eta^2_p = .528$; and SLI versus VM, $F(1, 38) = 65.717$, $p < .0001$, $\eta^2_p = .634$. Children with SLI scored significantly below both groups of typically developing controls on both receptive and expressive vocabulary standard scores: SLI versus CAM receptive vocabulary, $F(1, 38) = 17.284$, $p < .001$, $\eta^2_p = .313$; SLI versus CAM expressive vocabulary, $F(1, 38) = 19.036$, $p < .001$, $\eta^2_p = .334$; SLI versus VM receptive vocabulary, $F(1, 38) = 40.330$, $p < .001$, $\eta^2_p = .515$; and SLI versus VM expressive vocabulary, $F(1, 38) = 84.388$, $p < .001$, $\eta^2_p = .690$ (described above). In a similar way, children with SLI scored lower than CAM peers on both NWR, $F(1, 38) = 3.85$, $p = .057$, $\eta^2_p = .092$, and CLPT, $F(1, 38) = 17.417$, $p < .0001$, $\eta^2_p = .320$. However, they did not differ from VM peers on either measure: NWR, $F(1, 38) = 0.057$, $p = .813$, $\eta^2_p = .013$; CLPT, $F(1, 38) = 0.401$, $p = .531$, $\eta^2_p = .010$. The NWR and CLPT results show that children with SLI have phonological and verbal working memory scores lower than those of CAM peers but comparable to those of younger, vocabulary-matched peers. The current study replicates earlier work showing a NWR deficit relative to CAM peers but not relative to VM peers (Munson et al., 2005).

Stimuli

Stimulus materials were web-based, publicly available clip-art pictures of 45 familiar nouns with CVC labels, varying orthogonally in WF and PPF. WF counts were taken from the Hoosier Mental Lexicon (Nusbaum, Pisoni, & Davis, 1984), which uses frequency counts from the Brown corpus (Kuera & Francis, 1967). The 1,099 English CVC words rated high in familiarity were separated into high- and low-WF groups. PPF was based entirely on PP, as estimated from the Brown corpus in the Child Language Data Exchange System (CHILDES) database (Brown, 1973; MacWhinney, 1991). PPF was calculated for each CVC word as the product of (a) the probability of a word starting with the first consonant; (b) the probability of the vowel, given that first consonant; (c) the probability of the second consonant, given that vowel; and (d) the probability of a word boundary, given that final consonant (Coady & Aslin, 2004). That is, the PPF measure takes into account both positional segment frequency and phoneme co-occurrence frequency. Although PPF was based solely on PP, ND was also measured because these two variables are necessarily correlated. The same 1,099 CVC words were separated into high- and low-PPF groups. A total of 45 picturable words constituted four groups: (a) 15 high-WF, high-PPF words; (b) 13 high-WF, low-PPF words; (c) nine low-WF, high-PPF words; and (d) eight low-WF, low-PPF words. A description of the stimulus words is provided in the Appendix.

It was important to ensure that WF and PPF were truly orthogonal; thus, groups of words were compared in terms of log-WF, log-PPF, and log frequency-weighted neighborhood density (LFWND; calculation described in Coady & Aslin, 2003). High- and low-WF words differed in log-WF, $F(1, 40) = 169.57$, $p < .0001$, $\eta^2_p = .809$, but not in log-PPF, $F(1, 40) = 1.22$, $p = .28$, $\eta^2_p = .030$, or LFWND, $F(1, 40) = 0.006$, $p = .94$, $\eta^2_p = 0$. High- and low-PPF words did not differ in log-WF, $F(1, 40) = 1.95$, $p = .17$, $\eta^2_p = .047$, but did differ in log-PPF, $F(1, 40) = 162.41$, $p < .0001$, $\eta^2_p = .802$, and LFWND, $F(1, 40) = 23.99$, $p < .001$, $\eta^2_p = .375$. As expected, high-PPF words came from denser neighborhoods than did low-PPF words.

Procedure

Children participated in the picture-naming task as part of a larger experimental protocol. The experiment was conducted in a quiet room and involved two phases—familiarization and testing. During familiarization, children saw printed cards, approximately 4 in. square, showing the actual pictures. Children were instructed to name pictures as quickly and accurately as possible. When children produced a nontarget word, they were given the target label. For example, a common response to the picture of a rat was the word *mouse*. In that case, children were told that the picture actually showed a rat. Children also were instructed to produce responses without any extraneous information, such as articles (e.g., *a cat*) or diminutives (e.g., *doggy*). The testing phase commenced when the children could reliably name pictures.

Testing was conducted through the use of PsyScope (Cohen, MacWhinney, Flatt, & Provost, 1993) on an Apple iMac G4 running OS9. PsyScope was programmed to display pictures and to measure children's response times via a voice-activated microphone attached to a button box (New Micros, Dallas, TX). Children were positioned directly in front of the

computer and wore two lapel microphones—one attached to the button box to measure response times, and a second attached to a minidisk recorder for subsequent transcription. They were told that the same pictures from the familiarization phase would be shown on the computer screen, and they were instructed to name the pictures as quickly and accurately as possible. The experimenter then initiated experimental trials. Pictures appeared on screen, one at a time, and remained until the child vocalized a response. When the button box registered a vocal response, the picture was removed, leaving a blank computer screen. The next trial began when the experimenter pushed a computer key. That is, the experimenter controlled the pace of the experiment. The entire experimental session was recorded via the second lapel microphone attached to a minidisk recorder.

Children's responses were transcribed from recordings of the experimental sessions. Whole words were transcribed through the use of English orthography. CVC words were scored in a binary fashion as either correct or incorrect (1 or 0, respectively). Because stimulus items were real words, and because none of the children had articulation difficulties, cases in which a child missed a single segment were counted as errors. Interscorer reliability was calculated after a second listener re-transcribed sessions for four randomly chosen children from each group (20% of the data). Transcription agreement was 97.98% for children with SLI, 99.60% for VM children, and 96.77% for CAM children.

Results

Item Analysis

As a check on item imaginability, accuracy and naming times were calculated for each picture individually. Any picture that either was not named consistently with the target label or was named inordinately slowly was judged to be a poor stimulus item and was removed from subsequent analyses. Item accuracy and naming times for correct responses were calculated by examining scores for all 60 participants for each picture. Two *z* scores were then calculated for each item—one for accuracy and another for naming latency. Mean item accuracy was 92.0% ($SD = 6.5$). One picture, that for *jar* (low WF, high PPF), was named correctly by only 44 children (73.33%), for a *z* score of -2.89 . Thus, this item was removed from all subsequent analyses. Mean item naming time for correct responses was 1,340 ms ($SD = 232$). No items were statistical outliers; thus, none were removed on the basis of naming time scores.

Accuracy

Group accuracy results are presented in Figure 1. Accuracy results were entered into a three-way, mixed-design analysis of variance (ANOVA), with group as the between-subjects factor and WF and PPF as within-subjects factors. This ANOVA revealed that only WF affected naming accuracy, $F(1, 57) = 16.763$, $p < .0001$, $\eta^2_p = .227$. All children named pictures with high-WF labels more accurately than they did for those with low-WF labels. There were no significant accuracy differences due to group, $F(2, 57) = 0.245$, $p = .78$, $\eta^2_p = .009$, or PPF, $F(1, 57) = 0.077$, $p = .78$, $\eta^2_p = .001$. Furthermore, none of the interactions were significant: WF $\times$ Group, $F(2, 57) = 0.197$, $p = .82$, $\eta^2_p = .007$; PPF $\times$ Group, $F(2, 57) = 0.022$, $p = .98$,

$\eta^2_p = .001$; $WF \times PPF$, $F(1, 57) = 0.958$, $p = .33$, $\eta^2_p = .017$; and $WF \times PPF \times Group$, $F(2, 57) = 0.678$, $p = .51$, $\eta^2_p = .023$.

Naming times—Naming times for correct responses were analyzed. Ulrich and Miller (1994) pointed out that reaction time results tend to have a positive skew, with spuriously large values being common. In the current experiment, 23 correct responses occurred after a 5-s latency, and six correct responses occurred after a 10-s latency. The concern is that these large reaction times reflect processes other than those required to name pictures, such as breaks in attention. Ulrich and Miller made a number of recommendations meant to minimize the effects of spurious outliers. First, they suggested that reaction time results be submitted to a natural-log transformation meant to correct for the positive skew. Second, they discussed data truncation strategies such as accommodation or identification.

Accommodation refers to using a summary measure such as the median, which should be relatively uninfluenced by abnormally small or large reaction times. *Identification* refers to eliminating outliers that exceed an a priori cutoff. Third, they acknowledged that truncation itself may introduce distortion by weakening potential relationships between reaction times and independent variables. Analyses of (a) means of raw reaction times (untransformed and nontruncated), (b) means of natural-log transformed reaction times (without truncation), (c) medians of untransformed reaction times, and (d) means of untransformed reaction times (with outliers removed) all produced very similar results. For the sake of brevity, only the results of natural-log transformed reaction times are presented. Those results are the most representative because each significant finding was also significant in at least two of the other three analyses.

Group raw reaction time results are presented in Figure 2. For each child, means of natural-log transformed naming times for the four word types were entered into a mixed-design ANOVA, with WF and PPF as within-subjects factors and group as the between-subjects factor. This analysis revealed a significant main effect of group, $F(2, 57) = 4.755$, $p < .05$, $\eta^2_p = .143$. The difference between CAM children and those with SLI (the CAM group was faster than the group of children with SLI) only approached significance, $F(1, 38) = 3.275$, $p = .078$, $\eta^2_p = .079$. However, the CAM group named pictures significantly more quickly than did the VM group, $F(1, 38) = 12.892$, $p = .001$, $\eta^2_p = .253$. The difference between children with SLI and VM children was not significant, $F(1, 38) = 0.894$, $p = .35$, $\eta^2_p = .023$. All children named pictures with high-WF labels more quickly than they did pictures with low-WF labels, $F(1, 57) = 18.367$, $p < .0001$, $\eta^2_p = .244$. This effect was comparable for all three groups, based on the nonsignificant $Group \times WF$ interaction, $F(2, 57) = 1.006$, $p = .37$, $\eta^2_p = .034$. The main effect of PPF was not significant, $F(1, 57) = 0.732$, $p = .40$, $\eta^2_p = .013$. However, the $Group \times PPF$ interaction was significant, $F(2, 57) = 3.896$, $p = .026$, $\eta^2_p = .120$. Follow-up analyses revealed that PPF affected naming times only for children with SLI, $F(1, 19) = 6.188$, $p = .022$, $\eta^2_p = .246$, and not for the CAM group, $F(1, 19) = 1.546$, $p = .229$, $\eta^2_p = .075$, or the VM group, $F(1, 19) = 0.027$, $p = .870$, $\eta^2_p = .001$. There was also a significant $WF \times PPF$ interaction, $F(1, 57) = 16.173$, $p < .0001$, $\eta^2_p = .221$. Exploration of this interaction revealed that for high-WF words, those with high-PPF labels were named more quickly, $F(1, 57) = 9.606$, $p < .01$, $\eta^2_p = .144$. However, for low-WF

words, those with high-PPF labels were named more slowly, $F(1, 57) = 9.964, p < .01, \eta^2_p = .149$. This interaction did not vary by group, $F(2, 57) = 0.693, p = .50, \eta^2_p = .024$.

Finally, a mixed-design analysis of covariance was run, with maternal education as the covariate. In this analysis, main effects due to WF and PPF remained significant: WF, $F(1, 51) = 5.683, p < .05, \eta^2_p = .118$, and PPF, $F(1, 51) = 6.824, p < .05, \eta^2_p = .100$. However, the WF $\times$ PPF interaction was no longer significant, $F(1, 51) = 0.625, p = .433, \eta^2_p = .012$. Planned comparisons examined this interaction for each of the three groups. For children with SLI, entering maternal education as a covariate resulted in a nonsignificant WF $\times$ PPF interaction, $F(1, 16) = 1.24, p = .281$. This pattern of results held for both control groups: CAM children, $F(1, 15) = 1.83, p = .196$; VM children, $F(1, 18) = 0.15, p = .701$. That is, effects due to maternal education were comparable for all three groups.

Discussion

The purpose of the current study was to explore potential lexical factors that influence picture naming by children with SLI. The study focused specifically on two sources of language knowledge known to affect spoken language processing—WF and PPF. To this end, a group of school-age children with SLI, a group of typically developing children matched on chronological age, and a group of younger, typically developing children matched on expressive vocabulary named pictures whose labels varied in both WF and PPF. To explore potential group differences in picture naming, both accuracy and naming time results were analyzed. Accuracy results revealed no group differences, suggesting that children with SLI knew and could produce picture labels on a par with those produced by both groups of typically developing children. In fact, the only significant finding related to accuracy was the main effect of WF. All children named pictures whose labels occur frequently in the language environment more accurately than they did pictures with infrequently occurring labels. The nonsignificant Group $\times$ WF interaction showed that the magnitude of this effect was comparable for all three groups.

Although the accuracy results did not demonstrate a naming deficit, results from analyses of naming times were more revealing. In order to correct for the positive skew typical of reaction times, results were natural-log transformed. This analysis revealed a main effect of group. The difference between CAM controls and children with SLI approached significance ($p = .078$), but the difference was more robust for CAM and VM children. This pattern approximates the results of previous picture-naming studies (Lahey & Edwards, 1996; Leonard et al., 1983). However, there were no naming-time differences between children with SLI and younger VM children; these results fail to replicate those from Leonard and colleagues' previous study (1983). Two potential explanations for this discrepancy are (a) differences in matching criteria between the two studies and (b) group differences in nonverbal intelligence in the current study. First, Leonard and colleagues matched children on the basis of composite language age, whereas the children in the current study were matched on raw scores from the standardized expressive vocabulary measure. The current results suggest that naming times as a whole are related to expressive vocabulary. However, the two groups of children matched on vocabulary showed different sensitivity to the lexical variable PPF, so vocabulary alone cannot account for the naming time results. Second, the

younger children in the current study were matched to the group of children with SLI on the basis of raw expressive vocabulary scores, but this matching criterion resulted in group differences in nonverbal intelligence. The nonverbal scores for the group of VM children were significantly higher than those for the group with SLI. This may potentially explain why the difference between children with SLI and VM controls was attenuated in the current study. Children in the current study named pictures with frequently occurring labels more quickly than they did those with infrequent labels. Furthermore, the magnitude of this effect was comparable for all three groups of children, as indicated by nonsignificant Group $\times$ WF interactions. This finding replicates findings from Leonard and colleagues' earlier study using the picture-naming task (1983) as well as those from a number of other studies using a variety of tasks. A consistent finding in the literature is that children with SLI perform less well than typically developing children but still show comparable effects due to WF. This pattern of results has been documented for a past-tense marking task (Norbury et al., 2001), a gating task (Mainela-Arnold et al., 2008), a dual-processing verbal working memory task (Mainela-Arnold et al., 2010a), and a verbal free-recall task (Coady et al., 2013).

There was no main effect due to PPF. However, there was a significant Group $\times$ PPF interaction, which revealed that PPF effects were limited to children with SLI. For children with SLI, PPF exerted an inhibitory effect, with slower naming for words with high PPF, which was consistent with results from previous studies (Newman & German, 2002). Neither control group showed a main effect of PPF. There was also a significant WF $\times$ PPF interaction, which revealed that PPF facilitated naming of pictures with high-WF labels but inhibited naming of pictures with low-WF labels. The nonsignificant three-way interaction showed that this two-way interaction was comparable for all three groups. Although this interaction pattern has been reported previously (Coady et al., 2010b; Frank, Tanenhaus, Aslin, & Salverda, 2007; Vitevitch & Rodríguez, 2005), it is not the typical WF $\times$ PPF interaction. A more frequent WF $\times$ PPF interaction occurs when PPF (in the form of ND) exerts an inhibitory effect on both high- and low-WF words, but with a larger effect for low-WF words (Luce & Pisoni, 1998; Luce, Pisoni, & Goldinger, 1990; Vitevitch & Sommers, 2003). Presumably, WF effects are weaker for low-WF words relative to high-WF words, allowing PPF to exert a stronger inhibitory effect for these low-WF words. Yet another pattern occurs in gating studies (Mainela-Arnold et al., 2008; Metsala, 1997), in which PPF (again in the form of ND) exerts an inhibitory effect on high-WF words but a facilitatory effect on low-WF words. According to Metsala, this pattern of results arises from two distinct sources—the competition effects described above as well as effects due to developmental changes in the specificity with which lexical items are represented. High-PPF words share phonetic overlap with many other words, so children must attend to phonological detail in order to discriminate them from other similar-sounding words. Because high-PPF words are stored with a high level of phonological detail, WF effects are minimal. However, there is not as much need to incorporate phonetic detail into low-PPF words. Consequently, WF effects are greater for low-PPF words.

The results of the current study evidence yet another WF $\times$ PPF interaction, in which the frequency of words' phonological patterns exerts a facilitatory effect for high-WF words but an inhibitory effect for low-WF words. Performance is best in the case whereby WF and PPF conspire to enhance naming times. It is worse in the case where by WF is low and thus

offers minimal support, whereas PPF is high and thus causes increased competition. A similar WF $\times$ PPF interaction occurs in studies of real-word recall. Hulme and colleagues (1997) investigated adults' recall of high- and low-WF words and reported an advantage for high-WF words. Roodenrys and colleagues (Roodenrys et al., 2002) showed a similar recall advantage for words from dense phonological neighborhoods and for words from high-frequency neighborhoods—that is, a high-PPF advantage. WF effects (Henry & Millar, 1991; Majerus & Van der Linden, 2003) and PPF effects (via ND effects; Thomson, Richardson, & Goswami, 2005) also have been reported for children with typical language development. When both factors are considered together, a comparable interaction results (Coady et al., 2013). The significant Group $\times$ PPF interactions revealed that children with SLI were more susceptible to competition effects as a result of PPF relative to both groups of typically developing controls. Specifically, children with SLI were particularly slow at naming low-frequency words that share phonetic overlap with many other words. Findings from previous studies showed that children with SLI exhibit facilitatory PP effects that are comparable to typical controls (Coady et al., 2010a, 2010b). However, other reports suggest that the children with SLI exhibit larger inhibitory ND effects than do typical controls (Mainela-Arnold et al., 2008). In this case, it might be more useful to set aside the distinction between ND and PP effects and instead consider facilitatory versus inhibitory effects that are due to PPF. In the current study, children named pictures whose labels differed in PPF, or the frequency of their phonological patterns. Inhibitory effects due to PPF were greater in children with SLI relative to both groups of typically developing peers. Specifically, children with SLI named pictures with low-WF labels with many lexical competitors (high-PPF labels) inordinately more slowly than did both control groups. In their gating study, Mainela-Arnold and colleagues (2008) also noted that children with SLI were more vulnerable to competition from structurally similar items. The authors reported that children with SLI were able to identify spoken words with as little acoustic information as those used by typically developing peers. However, the children with SLI were more likely to change their guess at later gate durations, suggesting that they were keeping competitors active for a longer period of time.

Two lines of research help to explain this finding that children with SLI are more susceptible to interference from structurally similar words. First, studies examining speech perception reveal that children with SLI have more overlap between adjacent phonetic categories, as measured by shallower identification functions in categorical perception tasks, relative to typically developing peers (Coady, Evans, Mainela-Arnold, & Kluender, 2007; Joanisse, Manis, Keating, & Seidenberg, 2000; Sussman, 1993; Thibodeau & Sussman, 1979). This finding has implications for spoken word recognition in that it leads to activation of a greater number of competitors, resulting in potentially slower and less accurate identification of the target word. Consider a listener hearing the word *bowl*. Besides the target word, a number of words sharing phonetic overlap are also activated, including *pole*, *goal*, *bill*, *bull*, *boat*, and *bone*. Identifying the target word involves choosing it from this pool of competitors. For a listener with more overlap between phonetic categories, words sharing overlap with those competitors will also be activated, including words sharing overlap with *pole* such as *pill*, *pull*, *pose*, and *poach*; words sharing overlap with *goal* such as *gale*, *gal*, *goat*, and *goat*; and so forth. Therefore, resolving the target word's identity involves picking it out from an even

greater number of competitors, with a resulting decrease in accuracy and increase in naming times. The second factor that may help explain slower word identification is that children with SLI are less able to exploit statistical regularities in their input (Evans, Saffran, & Robe-Torres, 2009). After 21 min of exposure to an artificial language containing no overt cues to word boundaries, typically developing children were able to use statistical regularities to identify word boundaries, whereas children with SLI were at chance. Children with SLI required an additional 42 min of exposure to succeed, suggesting that they are less sensitive to statistical regularities in their input. This relates to the current study because PPF is itself a statistical regularity that must be gleaned from the input.

In addition to differing in language status, the groups also differed in maternal education. Specifically, maternal education was lower for children with SLI than for both control groups. One concern is that findings for children with SLI are influenced by maternal education. Reanalysis of the naming times of children with SLI who had maternal education entered as a covariate resulted in a nonsignificant $WF \times PPF$ interaction, reflecting a lack of differential effects due to PPF for high- versus low-WF words. At first glance, this suggests that PPF effects are driven by maternal education. However, reanalysis of each control group revealed a similar pattern. Although maternal education was lower for children with SLI, effects due to maternal education were comparable for all three groups. Generally speaking, maternal education affects the amount of language input that children receive (Hart & Risley, 1995; Hoff, 2003). For the current study, mothers of children with SLI had less formal education, suggesting that their children receive less input from which they must extract these statistical phonological regularities. Because children with SLI potentially receive less language input, and because they are less able to extract information about PPF and other statistical regularities from that input, a different pattern of results was evidenced. In this case, children with SLI had inordinately slower naming of pictures whose labels were low-frequency words with high-frequency phonological patterns. Reduced input, reduced sensitivity to that input, and greater overlap among similar-sounding words are all likely contributors to slower picture naming by children with SLI.

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Appendix

Description of Stimulus Words

Word	WF	LOG PPF	LFWND	NUM NEI	NEI FREQ
High WF–high PPF					
<i>ball</i>	128	−3.89	84.89	22	4,778
<i>bat</i>	41	−3.00	139.45	31	22,753
<i>bear</i>	264	−3.42	90.49	23	5,630
<i>bed</i>	140	−4.49	82.77	22	3,830
<i>car</i>	393	−4.11	79.18	20	5,502
<i>cat</i>	42	−3.40	118.65	27	17,230
<i>cup</i>	63	−4.29	53.57	14	3,661
<i>door</i>	348	−3.61	83.66	22	3,990
<i>girl</i>	374	−4.44	35.66	12	179
<i>hair</i>	161	−3.41	88.63	22	6,974
<i>house</i>	715	−4.14	25.63	7	885
<i>lake</i>	61	−4.05	105.33	27	5,716
<i>man</i>	1,377	−4.20	81.77	21	3,832
<i>sun</i>	321	−3.76	86.78	21	8,484
<i>watch</i>	240	−4.05	22.18	5	4,733
High WF–low PPF					
<i>church</i>	451	−6.56	19.31	6	122
<i>dog</i>	148	−5.26	16.60	5	436
<i>food</i>	198	−6.78	30.14	10	351
<i>judge</i>	123	−7.00	10.72	4	16
<i>leaf</i>	34	−6.48	56.79	16	2,157
<i>leg</i>	126	−5.82	44.28	13	1,329
<i>match</i>	101	−5.57	51.54	14	2,627
<i>moon</i>	64	−5.52	57.00	15	3,587
<i>pool</i>	135	−5.67	44.69	14	819
<i>road</i>	302	−5.87	74.06	22	1,358
<i>room</i>	443	−5.85	66.35	21	594
<i>ship</i>	154	−6.41	48.84	16	592
<i>teeth</i>	102	−5.88	23.41	8	297
Low WF–high PPF					
<i>bun</i>	9	−3.84	108.82	27	7,693
<i>fin</i>	8	−4.05	109.82	24	24,690
<i>goat</i>	8	−4.20	60.56	16	3,641
<i>jar^a</i>	2	−4.48	52.55	13	5,672
<i>kite</i>	1	−4.32	64.13	17	3,655
<i>mat</i>	7	−3.51	102.55	23	18,733
<i>mop</i>	11	−4.23	35.11	12	491
<i>rat</i>	10	−4.04	132.34	30	18,564
<i>wheat</i>	9	−4.18	96.97	24	7,557

Word	WF	LOG PPF	LFWND	NUM NEI	NEI FREQ
Low WF–low PPF					
<i>bib</i>	2	–7.31	38.52	10	3,174
<i>chalk</i>	4	–6.00	35.50	11	904
<i>dice</i>	1	–5.65	38.08	13	524
<i>goose</i>	7	–6.51	28.23	9	659
<i>mug</i>	3	–5.69	48.44	15	1,062
<i>pig</i>	14	–5.37	51.70	17	731
<i>van</i>	2	–5.69	38.96	10	3,478
<i>web</i>	6	–8.12	32.84	8	4,444

Note. Stimulus words include word frequency (WF; Kuera & Francis, 1967), log phonotactic pattern frequency (LOG PPF; described in Coady & Aslin, 2004), log frequency-weighted neighborhood density (LFWND), number of neighbors (NUM NEI), and neighborhood frequency (NEI FREQ; neighborhood variables described in Coady & Aslin, 2003).

^aThe stimulus item *jar* was removed from all analyses because of low naming accuracy.

Figure 1.

Accuracy scores for children with specific language impairment (SLI), younger vocabulary-matched typical controls (VM), and chronological age-matched typical controls (CAM) in the picture-naming task. Target words differed in word frequency (WF) and phonotactic pattern frequency (PPF). hiPPF = high phonotactic pattern frequency; loPPF = low phonotactic pattern frequency; hiWF = high word frequency; loWF = low word frequency.

Figure 2.

Raw, untrimmed naming times for pictures varying in word frequency (WF) and phonotactic pattern frequency (PPF). RT = reaction time.

Table 1

Group summary statistics for children with specific language impairment (SLI), typically developing children matched for expressive vocabulary (VM), and typically developing children matched for chronological age and nonverbal IQ (CAM).

Measure	Children with SLI	VM children	CAM children
Age	9;8 (1;6)	6;8 (0;9)	9;7 (1;8)
Maternal education ^a	13.8 (1.7)	16.8 (2.5)	16.6 (3.3)
CELF-3 ELS	72.3 (10.1)	111.1 (12.4)	106.5 (11.1)
CELF-3 RLS	68.1 (11.2)	—	—
CELF-3 C&D	5.4 (1.7)	10.8 (2.5)	10.0 (2.7)
PPVT-III	89.9 (9.7)	109.0 (9.3)	101.9 (8.5)
EVT	83.8 (9.2)	107.8 (7.2)	98.0 (11.3)
Leiter-R	97.9 (8.5)	111.9 (6.7)	99.6 (5.7)
NWR	72.6 (11.0)	75.1 (11.7)	79.4 (11.0)
CLPT	29.4 (18.8)	32.9 (15.6)	50.6 (12.1)

Note. Means (with *SDs*) are presented for chronological age (years;months); maternal education level (years of education); composite expressive (ELS) and receptive (RLS) language scores on CELF-III; standard scores on the Concepts and Directions (C&D) subtest of the CELF-III; standard scores on the PPVT-III, EVT, and Leiter-R; percent phonemes correct on NWR; and percent final words recalled on CLPT. Dash indicates that data were not collected for this measure. CELF-3 = Clinical Evaluation of Language Fundamentals, Third Edition; PPVT-III = Peabody Picture Vocabulary Test—III; EVT = Expressive Vocabulary Test; Leiter-R = Leiter International Performance Scale—Revised; NWR = Nonword Repetition Task; CLPT = Competing Language Processing Task.

^aMaternal education was not reported for five children—two with SLI and three CAM controls.