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Effect of Phonotactic Probability and Neighborhood Density on Word-Learning Configuration by Preschoolers With Typical Development and Specific Language Impairment

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Abstract

Purpose: In this study, the authors assessed the effects of phonotactic probability and neighborhood density on word-learning configuration by preschoolers with specific language impairment (SLI) and typical language development (TD).

Method: One hundred thirty-one children participated: 48 with SLI, 44 with TD matched on age and gender, and 39 with TD matched on vocabulary and gender. Referent identification and naming were assessed in a computer-based learning context.

Results: For referent identification, preschoolers with TD benefited from high phonotactic probability, and the younger group also benefited from low neighborhood density. In contrast, the SLI group benefited only from high neighborhood density. For naming, older preschoolers with TD benefited most from low-density words, younger preschoolers with TD benefited most from words with high phonotactic probability, and the SLI group showed no advantage.

Conclusion: Phonotactic probability and neighborhood density had different effects on each group that may be related to children's ability to store well-specified word forms and to the size of their extant lexicon. The authors argue that cross-study comparisons of word learning are needed; therefore, researchers should describe word, referent, and learner characteristics and the learning context and should situate their studies in a triggering → configuration + engagement model of word learning.

Keywords

children; language disorders; specific language impairment; language; development

Word learning comes easily for most children—but not for many children with specific language impairment (SLI; see Kan & Windsor, 2010, for a review). The more we understand about the complex process of word learning, the more likely we are to design effective treatments for children with SLI. One barrier to understanding is the lack of a cohesive model that defines the stages of word learning. Without this model, it is difficult to compare results across studies because the term *word learning* subsumes multiple word-learning stages.

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In 2010, Hoover, Storkel, and Hogan proposed that the work of Leach and Samuel (2007) could serve as a possible model to explain “the general components of word learning for any learner” (p. 100). Leach and Samuel introduced two concepts that they termed *configuration* and *engagement*. They used these terms to describe the lexical acquisition process in adolescent or adult language users. Acknowledging that a word is added to the lexicon incrementally, they proposed that configuration of a lexical entry includes learning a word’s phonological form, and/or orthographic form, its meaning; and its syntactic role. They stated that “the lexical configuration is the set of factual information that one knows about a word” (p. 2) and that it develops over time but is static at any specific moment in time.

During lexical configuration, the learner creates and stores a stable, sufficiently specified word form and semantic representation (and link between them) to permit recognition of the word, its referent, and their association when the word or referent is re-presented. This stage may be particularly challenging for children with SLI who are known to have difficulty (a) encoding phonological information (Bishop, North, & Donlan, 1996; Edwards & Lahey, 1998), (b) creating and storing phonological and semantic representations of words (Alt & Plante, 2006; Gray, 2005), and (c) creating links between phonological and semantic representations (Kail & Leonard, 1986).

Leach and Samuel (2007) defined *lexical engagement* as “how the lexical representation behaves dynamically, over a much shorter time scale” (p. 2). Thus, lexical engagement is demonstrated when one word in the lexicon affects another, as shown by phonological or semantic priming experiments. Presumably, lexical engagement cannot proceed without successful word-form storage during configuration.

It is worth noting that others have also differentiated among stages in the word-learning process. Carey and Bartlett (1978) described fast mapping as a process that occurs when a word is encountered for the first time and the learner creates an initial phonological representation, forms hypotheses about meaning, and creates a link between the phonological and semantic representations. Thus, fast mapping overlaps configuration. Carey (1978) described slow mapping as a process whereby children develop more robust phonological, lexical, and semantic representations as they experience repeated exposures to words in varying contexts. This is akin to Leach and Samuel’s (2007) configuration but may also overlap with lexical engagement. To the concepts of lexical configuration and engagement, Hoover et al. (2010) added triggering, which precedes both. They defined *triggering* as “identifying a word as novel so as to initiate learning” (p. 101). They reasoned that on hearing a novel word, phonological (individual sounds) and lexical (whole word-form) representations are activated. If the listener recognizes that the word form is new (no identical word form stored in the listener’s lexicon), word learning should be triggered. Lexical configuration begins immediately after learning is triggered with the “creation of a new lexical representation” (p. 100).

This triggering → configuration + engagement model of word learning could potentially be expanded to include all phonological and semantic aspects of word learning. One advantage of placing word-learning studies within this framework is that it would permit clearer comparisons of methods and findings across studies. Indeed, Leach and Samuel (2007)

complained that to understand lexical development, one should “take a more systematic approach, both theoretically and experimentally” (p. 2). A second advantage is that by systematically studying each stage of word learning, one can identify where the word-learning process breaks down for children with SLI.

Within each stage of word learning, it is important to consider four factors that may affect learning rate and overall success: the abilities and experience the learner brings to the task (participant characteristics), the characteristics of the words to be learned, the characteristics of the referents, and the learning context. In this study, we focused on the interaction between participant and word characteristics by comparing learning rates and outcomes in children with SLI compared with (younger) vocabulary- and age-matched peers with typical language development (TD) using words with high or low phonotactic probability and neighborhood density. We did not study triggering, but we used triggering to initiate and study lexical configuration.

Effect of Phonotactic Probability and Neighborhood Density on Word-Learning Configuration in Children

Phonotactic probability is the likelihood that a particular sequence of sounds or sound segments will occur in a language (e.g., Jusczyk, Luce, & Charles-Luce, 1994). For example, in English the word *car* has relatively common sound sequences resulting in relatively high phonotactic probability. Sound sequences in the word *charm* occur more rarely in English; thus, *charm* has relatively low phonotactic probability. A number of studies have shown that children recognize and produce words with common sound sequences better than words with rare sound sequences (e.g., Edwards, Beckman, & Munson, 2004; Messer, Leseman, Boom, & Mayo, 2010; Munson, Swenson, & Manthei, 2005; Zamuner, Gerken, & Hammond, 2004).

Neighborhood density is a measure of how many words stored in the lexicon differ from another stored word by just one phoneme. For example, the word *mat* has many neighbors, including *rat*, *met*, and *mad*, so it resides in a relatively high-density neighborhood. The word *giant* has no neighbors that differ by a single phoneme, so it resides in a low-density neighborhood. Research has shown that words in sparse neighborhoods are recognized more easily than words in dense neighborhoods (e.g., Garlock, Walley, & Metsala, 2001; Metsala & Chisholm, 2010).

A criticism of word-learning studies is that many fail to consider phonotactic probability or neighborhood density when selecting words for experiments (Gray, Brinkley, & Sventina, 2012; Storkel, 2004). It is difficult to examine these word characteristics independently because they are highly correlated (Vitevitch, Luce, Pisoni, & Auer, 1999), and each can affect word learning differently (Gray, Brinkley, & Svetina, 2012). For example, Storkel and Lee (2011) proposed that phonotactic probability influences triggering because words with low phonotactic probability highlight the mismatch between stored and incoming representations. In contrast, they argued that neighborhood density plays a role in many stages of word learning, with words from low-density neighborhoods facilitating triggering and words from high-density neighborhoods facilitating engagement.

Owing in large part to the work of Storkel and colleagues (e.g., Storkel, 2001, 2003; Storkel & Lee, 2011; Storkel & Rogers, 2000), we have an emerging picture of how phonotactic probability and neighborhood density affect word-learning configuration in children with TD (see Table 1 for a summary of studies). In an early study, Storkel (2001) reported a high phonotactic probability advantage for preschoolers with TD for referent identification, form identification, and picture naming. Although the neighborhood density of the novel words was not reported, phonotactic probability and neighborhood density were correlated. Using the same methodology, Storkel (2003) demonstrated a high phonotactic probability advantage for production of novel verbs in preschoolers with TD. Storkel and Rogers (2000) found a high phonotactic probability advantage for referent identification in 10- and 13-year-olds with TD but no effect of phonotactic probability in 7-year-olds with TD. As in the 2001 study, the phonotactic probability and neighborhood density of words were correlated.

In contrast to the high phonotactic probability advantage found by Storkel and colleagues (Storkel, 2001, 2003; Storkel & Lee, 2011; Storkel & Rogers, 2000), our own initial work with preschoolers with TD and SLI (Gray & Brinkley, 2011) showed a low phonotactic probability advantage for referent identification and naming. No word in this experiment had a phonological neighbor; therefore, all were low-density words. In a methodological replication of Gray and Brinkley (2011), Gray, Brinkley, and Svetina (2012) found a similar low-probability advantage for wordlearning naming but no differences in phonotactic probability results for referent identification for TD and SLI groups. Important differences between our studies and those of Storkel and colleagues were that (a) they calculated phonotactic probability over the entire word, but we calculated it over one sublexical sequence within the word; (b) they used words with higher neighborhood density, whereas we used words with lower neighborhood density; (c) they provided fewer exposures than we did (5–7 vs. 105–132); (d) they used pictures as referents, whereas we used real objects as referents; and (e) their learning context was a storybook, whereas ours was play.

Storkel, Armbruster, and Hogan (2006) also found a low phonotactic probability advantage for picture naming by adults when they combined completely and partially correct responses and when they analyzed partially complete responses, but they found no significant difference for high or low phonotactic probability when only completely correct responses were analyzed. They also found a consistent high-density advantage. The low phonotactic probability advantage continued in an experiment by Storkel and Lee (2011), who assessed the independent effects of phonotactic probability and neighborhood density on word learning by 4-year-olds with TD. Referent identification and naming were both assessed; however, naming performance was at floor and prevented analysis of the results. In contrast to their previous findings, but consistent with Gray and Brinkley (2011), Storkel and Lee found a low phonotactic probability advantage in the referent naming task for words from medium-density neighborhoods. In their second experiment using the same methodology but words with medium phonotactic probability and high or low neighborhood density, they found no main effect of neighborhood density; however, there was a significant Neighborhood Density $\times$ Time interaction. Higher scores were achieved for nonwords from sparse neighborhoods than for those from dense neighborhoods after training, but the difference was not significant 1 week later. Results of these studies appear contradictory, but in fact they may be due to different manipulations of word characteristics.

Importance of Studying Phonotactic Probability and Neighborhood Density in Children With SLI

A recent meta-analysis of 28 word-learning studies of children with primary language impairment and their peers with TD showed consistently poorer performance by SLI groups, with the largest between-group effect sizes in high-exposure conditions (Kan & Windsor, 2010). This finding showed that lexical configuration is particularly challenging for children with SLI. The meta-analysis also showed a larger between-group effect size for comprehension (referent identification) than for naming tasks, suggesting that a detailed observation of comprehension learning during configuration could yield new information about the source of word-learning problems in these children. We do know that SLI groups often learn fewer words than their peers with TD, and they often require more exposures to words to reach learning criteria (e.g., Ellis Weismer & Hesketh, 1998; Gray, 2004; Rice, Cleave, & Oetting, 2000). It is important to note, however, that some children with SLI learn words as well as their peers with TD (Gray, 2004). To determine why, researchers are beginning to investigate the effect of learner, word, and referent characteristics on children with SLI.

Table 1 shows how factors known to affect word learning have varied across word-learning experiments investigating configuration in children. In particular, only one study has systematically manipulated both phonotactic probability and neighborhood density in preschool children with TD (Storkel & Lee, 2011), but no study has manipulated both in preschoolers with SLI. This undoubtedly contributes to different findings across studies and, in particular, our own results showing no between-group differences for TD and SLI groups when between-group differences are common in word-learning studies (Gray & Brinkley, 2011; Gray, Brinkley, & Svetina, 2012). Gray and Brinkley manipulated phonotactic probability but used only low-density words. Perhaps neighborhood density is the key to between-group differences. Therefore, the purpose of this study was to assess the effects of both phonotactic probability and neighborhood density on the configuration stage of word learning in preschoolers with SLI and their age- and vocabulary-matched peers with TD. We used the same nonwords as Storkel et al. (2006), selected for their systematic variation of phonotactic probability and neighborhood density. We were particularly interested in how these word characteristics affected the learning rate for each group, so we used a dynamic word-learning paradigm that assessed trial-by-trial learning for referent identification. This paradigm permitted a more detailed examination of the configuration process than in any previous study.

Method

Participants

One hundred thirty-one children participated: 48 with SLI, 44 with TD matched individually to preschoolers with SLI on age (± 3 months) and gender (AM group), and 39 with TD matched individually to preschoolers with SLI on raw vocabulary scores on the Expressive Vocabulary Test (Williams, 1997; ± 1 *SD*) and gender (VM group). Children with SLI were between the ages of 48 and 67 months and spoke English as their primary language

according to parent report. No child was bilingual. Of the children, 20% were Hispanic and 80% non-Hispanic; in addition 1% were Native American, 1% Asian; 5% Black; 65% White; 20% more than one race; and 8% race unknown. Table 2 provides descriptive information about the participants, including age, mothers' years of education, and a summary of test results. Parents consented to their child's participation in this study per Arizona State University Internal Review Board requirements for human subjects protection.

All children were recruited from public and private preschools and daycare centers. The children with SLI were receiving special education services for language impairment. All children met the following criteria as determined by an American Speech–Language–Hearing Association–certified speech–language pathologist:

1. Hearing within normal limits bilaterally (screening at 25 dB HL) at 500, 1000, 2000, and 4000 Hz (American Speech-Language-Hearing Association, 1997)
2. Normal nonverbal intelligence as indicated by a standard score of 75 on the Nonverbal scale of the Kaufman Assessment Battery for Children, Second Edition (Kaufman & Kaufman, 2004)
3. For children with SLI, no evidence of serious neurological problems or developmental disorder other than language, articulation, or phonological problems, as reported by the parent or teacher
4. Also for children with SLI, adequate speech intelligibility for applying the scoring procedures
5. For the AM and VM groups, normal speech, language, motor, and cognitive development as reported by parent and teacher

We administered the following additional speech and language tests to describe participants' speech and language skills: the Peabody Picture Vocabulary Test—III (Dunn & Dunn, 1997); the Expressive Vocabulary Test (Williams, 1997); the Structured Photographic Expressive Language Test—Preschool 2 (Dawson, Eyer, & Fonkalsrud, 2005); the Antonyms, Sentence Completion, and Paragraph Comprehension subtests of the Comprehensive Assessment of Spoken Language (Carrow-Woolfolk, 1999); and the Bankson–Bernthal Test of Phonology (Bankson & Bernthal, 1990). Scores and between-group comparisons are reported in Table 2.

We also administered Dollaghan and Campbell's (1998) 16-item nonword-repetition task to assess short-term phonological memory. Nonwords were presented via headphones with an attached microphone on a laptop computer. Responses were recorded digitally. Research assistants (RAs) transcribed children's productions from recordings, calculating the percentage of phonemes correct for each child. Distortions and sound additions were scored as correct, but sound substitutions and omitted phonemes were scored as incorrect. Results are reported in Table 2.

To calculate scoring reliability, 10% of standardized assessments, distributed evenly across groups, were double scored in real time or from videotape by a second trained RA. Point-to-point agreement was 99.03% (range = 95.91%—100%). Twenty-one percent of the nonword

repetition tasks were distributed evenly across groups and were double scored from recordings. Point-to-point agreement for percentage of phonemes correct was 88.81% (range = 79.17%—96.88%).

Materials

Words.—Sixteen CVC nonwords used previously by Storkel et al. (2006) were divided into four sets of words on the basis of ratings of phonotactic probability and neighborhood density: (a) high probability, high density; (b) high probability, low density; (c) low probability, high density; and (4) low probability, low density. The nonword sets are listed in Table 3. Children had the opportunity to learn all four sets.

Referents.—The referents children learned to name were selected by collecting a variety of unique colored clipart figures. These figures were shown to three adults who were asked to name them. Any that elicited the same name from two or more adults were removed from consideration. Remaining figures were shown to nineteen 3- to 5-year-old children with TD to remove any that elicited the same name from more than half of the children. Final referents were organized into four sets of four referents each. The referents were grouped according to their visual features.

To ensure that referent set characteristics did not differentially affect word learning, we counterbalanced nonword set to referent set assignment within and across groups. In addition, we counterbalanced the order of presentation of the four nonword sets within and across groups. Finally, the nonword to referent assignment within each set was also counterbalanced across participants so that even when children within a group had the same nonword and referent set, they had many different nonword-referent pairings within sets.

Procedures

The assessments and experiment were conducted in a quiet room at the child's school or home with the RA working one on one with the child for about 1–1.5 hr per day. Children completed assessments before the word-learning experiment began. Assessments required about 2 days, depending on the age of the child. Each word set was learned over 2 consecutive days. Because some children were not available on consecutive days because of illness or absence from school, the mean time elapsed between the 2 days for each word set was 1.23 days (range = 1–13 days). All four word sets were typically completed within 2 weeks (median = 12 days; range = 7–52 days).

Familiarization phase (triggering).—Before presentations started for each word set, children completed a brief activity designed to trigger word learning and to provide an opportunity to hear how the child repeated the target words. During this activity, children were shown each referent printed on a flash card. As each card was presented, the RA said, “This is a *X*, say *X*.” If the child repeated the word correctly, the RA said, “Good, this is a *X*.” If the child repeated the word incorrectly, the RA noted the pronunciation (for later comparison to production scoring) and said, “Good try, this is a *X*.” Thus, children heard each word and saw it paired with its referent three times before they began the configuration portion of the study.

Referent identification.—For the referent identification portion of the word-learning experiment, children listened to the stimuli through a Sennheiser PC 151 audio microphone-earphone headset connected to a Dell laptop computer. The output of the earphones was calibrated to present the stimuli at about 65 dB SPL, which is consistent with a conversational level of speech at 1 m. An audio splitter allowed the RA to hear the stimuli on his or her headset. The custom laboratory software used by Pittman (2008, 2011) presented the experimental stimuli, recorded the trial-by-trial responses of the children, and provided feedback in a videogame format.

The child was seated beside the RA in front of the laptop computer monitor displaying the four target referents aligned vertically down the left third of the screen. The remaining portion of the screen contained a feedback game (e.g., puzzle, dot-to-dot) that advanced incrementally after each correct response. Each time the child heard a name and selected the correct referent, a new puzzle piece or segment of the dot-to-dot game was added. No puzzle piece or segment appeared after incorrect responses.

After the familiarization phase (described above), children were given the following instructions: “Next you will hear a name on the computer. When you hear the name, point to the picture that goes with the name. If you get it right, the game will play one step. If you get it wrong, nothing will happen.” Exposures for each nonword list were presented in four blocks, two per day, with a short break between blocks. Within each block, the four nonwords were presented randomly 15 times each for a total of 60 presentations. Thus, by the end of the four blocks for each word set the child had completed 240 referent identification trials.

Naming.—Naming trials were administered at the end of each word-learning block. The child was shown each of the four target referents on a flash card and asked to say its name. The child’s responses were recorded digitally via the headset microphone. By the end of the four blocks, the child had completed four naming probes for each nonword.

RAs scored productions from digital recordings using Adobe Audition Version 2 software. Each phoneme in each word was scored as correct or incorrect, with 48 possible phonemes correct for each word set (3 phonemes $\times$ 4 words $\times$ 4 trials). If the child produced the same phoneme substitution when imitating the word during the familiarization phase of the experiment and during the naming trials, it was not counted as incorrect. The child’s naming score was the percentage of phonemes correct for that word set.

Twelve percent of the word productions from each group were double scored by a second RA from the digital recordings. Point-to-point agreement for the percentage of phonemes correct was 96.24% (range = 83.33%–100%).

Results

Referent Identification

For referent identification analyses, data were reduced chronologically to 24 bins of 10 trials each. Performance in each bin was calculated as the percentage of correct responses. The

data were fit with the following equation to create exponential growth functions for each of the groups:

$$P_c = 1 - 0.75e^{-n/c}, \quad 1$$

where P_c is the probability of a correct answer, $1 - 0.75$ reflects chance performance for this task (25%), e is 2.718..., n is the midpoint of the trial block (5, 15, 25, etc.), and c is the time constant of the process. When $n = 0$ (beginning of the task), $P_c = .25$ (chance level). When the number of trials equals the time constant ($n = c$), performance is approximately 70.57% correct. This procedure adjusts estimates of c to minimize the sum of the squared deviations between the observed and the predicted points. The rate of learning (speed) is estimated as $1/n$ and indicates the progress toward the criterion performance with each trial. This procedure has the advantage of using all data points to determine the speed and trials to criterion for each child. Thus, the growth functions are used to characterize performance across trials, whereas the number of trials required to achieve 70% accuracy provides a single point to examine between- and within-group differences for word type.

Figure 1 shows the referent identification learning functions for each group by word type. Performance is plotted as a function of the number of trials in the referent identification task for the AM, VM, and SLI groups in the top, middle, and bottom panels, respectively. The parameter in each panel is word type, such that open and filled symbols represent high and low neighborhood density, respectively, and squares and circles represent high and low phonotactic probability, respectively.

As shown in Figure 1, the groups demonstrated different learning patterns. To determine whether these differences were significant within and between groups, the speed with which the children learned ($1/n$, where n = the number of trials to criterion) was log transformed and subjected to a repeated measures analysis of variance (ANOVA) with phonotactic probability (high, low) and neighborhood density (high, low) as the within-group factors and group (SLI, AM, VM) as the between-group factor. Significant main effects were found for phonotactic probability and group, as well as significant Phonotactic Probability $\times$ Group, Density $\times$ Group, and Probability $\times$ Density interactions (see Table 4). Pairwise comparisons with Bonferroni corrections for multiple comparisons revealed that high-probability words were associated with a significantly faster learning rate than low-probability words ($p < .001$), that the AM group had a faster learning rate than the VM group ($p < .001$), and that the SLI group had a faster learning rate than the VM group ($p = .002$), but the AM and SLI groups did not differ ($p = .152$).

We conducted post hoc repeated measures ANOVAs with Bonferroni corrections to assess word-type differences within each group (see Table 4). The AM group showed significant main effects for phonotactic probability, with significantly faster learning for high-probability words, but no effect of neighborhood density. The VM group showed the same main effect of probability but also a significant Probability $\times$ Density interaction, with faster learning rates for low-probability-low-density words than for low-probability-high-density words. The SLI group showed a markedly different pattern of results with a significant

neighborhood density effect, but no effect of phonotactic probability. That is, they learned high-density words significantly faster than low-density words.

The key finding from these analyses is that both the AM and the VM groups showed the fastest learning rates for high-probability words regardless of density, whereas the SLI group showed no phonotactic probability effect; rather, their fastest learning rate was for high-density words regardless of phonotactic probability.

We examined between-group differences for each word type using four separate univariate ANOVAs with Bonferroni corrections to highlight group similarities and differences. To facilitate group comparisons, we rearranged the learning functions from Figure 1 by word type; these are shown in Figure 2. For high-probability-high-density words, we found significant between-group differences ($p = .014$, $\eta_p^2 = .07$), with the AM group learning significantly faster than the VM group ($p = .012$). The SLI group did not differ from the AM or VM groups. For low-probability-high-density words, the groups differed significantly ($p < .001$, $\eta_p^2 = .25$) with the AM ($p < .001$) and SLI groups ($p < .001$) learning significantly faster than the VM group. For high-probability-low-density words, we found a significant group effect ($p = .001$, $\eta_p^2 = .10$) with a third pattern of performance emerging. The AM group learned significantly faster than both the VM ($p = .003$) and the SLI groups ($p = .004$), which did not differ. Finally, for low-probability-low-density words, groups differed significantly ($p < .001$, $\eta_p^2 = .16$), with a pattern of results similar to that for the high-probability-high-density words; in this case, however, both the AM ($p < .001$) and the SLI ($p = .008$) groups learned significantly faster than the VM group.

The key findings for these analyses are that for every word type, the learning rate of the AM group was significantly faster than that of the VM group. The learning rate of the SLI group was similar to that of the VM group for the high-probability words but similar to the AM group for the low-probability words, regardless of density.

Finally, it is interesting to note that after more than 240 presentations of each word type, the AM and SLI groups reached 90%–100% accuracy for referent identification for all word types; however, VM group accuracy remained less than 80% correct for low-probability words, regardless of density. This highlights the challenging nature of words low in phonotactic probability for younger children.

Naming

To analyze word naming, percentage of phonemes correct served as the dependent variable in a repeated measures ANOVA with phonotactic probability (high, low), neighborhood density (high, low), and time (1, 2, 3, 4) as the within-group factors and group (SLI, AM, VM) as the between-group factor. Planned post hoc comparisons for significant main effects used a Bonferroni correction for multiple comparisons. Results are reported in Table 5 and shown in the bottom panes of Figures 1 and 2.

We found significant main effects for phonotactic probability, neighborhood density, and time, with a significant Time $\times$ Group interaction (see Table 5). Scores for high-probability words ($M = .316$) were significantly higher than those for low-probability words ($M = .268$,

$p = .002$). Scores for low-density words ($M = .304$) were significantly higher than those for high-density words ($M = .279$, $p = .049$). Scores increased significantly from Time 1 ($M = .213$) to Time 2 ($M = .242$; $p = .007$) and from Time 2 to Time 3 ($M = .347$, $p < .0001$), but not from Time 3 to Time 4 ($M = .365$, $p = .105$).

Although we did not find significant Group $\times$ Phonotactic Probability or Group $\times$ Neighborhood Density interactions, we conducted planned follow-up repeated measures ANOVAs (see Table 5) to assess whether there were word-type differences within each group. For the AM group, we found a significant main effect of neighborhood density and time, but no significant interactions. The percentage of phonemes correct for low-density words ($M = .36$) was significantly higher than that for high-density words ($M = .31$, $p = .02$). Significant increases occurred only between Time 2 ($M = .27$) and Time 3 ($M = .41$, $p < .001$). Time 1 and Time 2 ($M = .24$) and Time 3 and Time 4 ($M = .43$) did not differ. Unlike the AM group, the VM group showed a significant main effect of phonotactic probability but no effect of neighborhood density. Time was also significant, and we found a significant Phonotactic Probability $\times$ Time interaction. The percentage of phonemes correct for high-probability words ($M = .30$) was significantly higher than that for low-probability words ($M = .22$, $p = .005$). Significant increases for time occurred from Time 2 ($M = .21$) to Time 3 ($M = .32$, $p < .001$). Time 1 and Time 2 ($M = .19$) did not differ, and Time 3 and Time 4 ($M = .34$) did not differ. The Phonotactic Probability $\times$ Time interaction was caused by the high-probability over low-probability advantage increasing at Time 4. The SLI group showed no effect of phonotactic probability or neighborhood density, only an effect of time. As with the other groups, significant increases occurred from Time 2 ($M = .24$) to Time 3 ($M = .31$, $p < .001$). Time 1 and Time 2 ($M = .21$) did not differ, and Time 3 and Time 4 ($M = .32$) did not differ.

Key findings are the lack of between-group differences for naming overall, although there was a Time $\times$ Group interaction, paired with the markedly different effects for phonotactic probability and neighborhood density across groups. The AM group showed a low-density advantage, the VM group a high phonotactic probability advantage, and the SLI group no advantage.

A comparison of results for referent identification and naming highlights the discrepancy that is common to wordlearning studies. As shown in Figures 1 and 2, even when referent identification reached 100% accuracy for a particular word type, production remained under 50% phonemes correct for each group.

Discussion

We designed this experiment to observe the configuration stage of word learning when the learner creates, stores, and links word-form and semantic representations. We systematically manipulated phonotactic probability and neighborhood density to determine whether these word characteristics affected learning differently for SLI, AM, and VM groups. To our knowledge, this was the first study to manipulate phonotactic probability and neighborhood density in this manner in preschool-age children and to measure their effects on referent identification and naming.

We did not necessarily expect phonotactic probability and neighborhood density to have the same effect on referent identification and naming because of different task demands and because phonotactic probability primarily affects sublexical representations (sound sequences and segments) and neighborhood density primarily affects lexical (whole-word) representations (Vitevitch et al., 1999). Across word-learning studies, referent identification scores are typically higher than naming scores because referent identification is easier. The child hears the word form and so does not have to retrieve it, but the child must remember which of four referents the word names. This requires a stable link between the word form and the semantic representation. In addition, the word form must be sufficiently specified to ensure that each time it is heard the child recognizes it as the same word. Naming is more difficult because the child sees the referent and does not have to retrieve the semantic representation but must retrieve and produce the word form. This requires a sufficiently specified word form to produce at least some of the phonemes and a stable link between the word form and semantic representation. We consider the different effects that phonotactic probability and neighborhood density may have on referent identification and naming in the sections below.

Referent Identification

The most important finding for referent identification was that phonotactic probability and neighborhood density affected learning differently for each group, as evidenced by significant Probability $\times$ Group, Density $\times$ Group, and Probability $\times$ Density interactions. We found that both TD groups showed a high phonotactic probability advantage, with the younger VM group also showing a low neighborhood density advantage. These results are not directly comparable to those of any previous studies, but findings are generally consistent with earlier studies by Storkel and colleagues (Storkel, 2001; Storkel & Rogers, 2000), who found a high-probability advantage in preschoolers and 10- and 13-year-olds with TD (but not 7-year-olds). Results for the VM group are also comparable to those of Storkel and Lee (2011), who found a low-density advantage in 4-year-olds for words with medium phonotactic probability, and to those of Gray and Brinkley (2011), who found a low-density advantage for TD and SLI groups. This is encouraging because it appears that when comparisons are restricted to the configuration stage of word learning in children with TD and when the factors being manipulated (or not) are clear (see Table 1), findings across studies are more consistent than previously thought.

Overall, we conclude that for preschoolers with TD, phonotactic probability trumps neighborhood density for referent identification, but neighborhood density also comes into play for younger children such that words from low-density neighborhoods will be learned faster than those from high-density neighborhoods. Why might this be? Previously, Vitevitch et al. (1999) hypothesized that phonotactic probability primarily affects processing of sublexical representations (sound sequences and segments) and that neighborhood density primarily affects lexical (whole-word) representations. High-probability sequences facilitate word processing, as shown by faster recognition and production by children and adults with TD. Hoover et al. (2010) proposed that in word-learning studies, high-probability sequences are held in working memory longer and perhaps more accurately than low-probability sequences, thereby speeding the creation and accuracy of stored word representations. Yet,

this sub-lexical processing advantage can be counteracted by a lexical competition disadvantage when similar word forms compete for retrieval. In high-density neighborhoods, this competition slows recall and production. This suggests that when both phonotactic probability and neighborhood density are manipulated, high-probability-low-density words should be learned fastest because of the advantages they convey on sublexical and lexical processing; however, Vitevitch et al. proposed that when nonwords are used in experiments, the phonotactic probability effect dominates because “nonwords fail to strongly activate competing lexical representations”(p. 308). This is consistent with our results for the AM and VM groups with TD.

In contrast, for referent identification the SLI group showed no phonotactic probability effect and a faster learning rate for high-density words. Why was no phonotactic probability effect found? We hypothesize that because of weaker short-term phonological memory (as evidenced by poorer SLI group performance on the nonword repetition task) and the possibility that children with SLI are less sensitive than their peers with TD to regularities in the language such as phonotactic probability (Evans, Saffran, & Robe-Torres, 2009), high-probability words did not convey a processing advantage over low-probability words. That is, they were not held in working memory longer or more accurately.

The processing advantage for high- versus low-probability words for the TD groups is illustrated quite clearly in Figure 2. Notice that for low-probability words, regardless of density, the learning rate for the AM and SLI groups does not differ significantly and learning rates for both groups are significantly faster than for the younger VM group. In effect, when the processing advantage conveyed by high phonotactic probability is taken away by presenting words with low phonotactic probability, the learning rate for both TD groups is slower, especially for the VM group, and the AM and SLI groups do not differ.

Why did the SLI group show a high-density advantage? Our hypothesis is that rather than creating and storing well-specified sublexical representations of words, the SLI group created and stored more holistic whole-word representations. In fact, this may be the norm for words in their existing lexicon. This hypothesis was tested in a recent priming experiment showing that preschoolers with SLI lacked sufficient detail in their phonological representations to support phonological priming, even though their AM and VM peers with TD showed a clear phonological priming effect (Gray, Reiser, & Brinkley, 2012). If this is the case, it follows that words from high-density neighborhoods would be learned faster than those from low-density neighborhoods because density affects lexical representations. Words from high-density neighborhoods activate more stored word forms than words from low-density neighborhoods, thus helping to maintain the new word form in working memory, which is important for storing and elaborating the lexical representation.

One additional factor could contribute to the high-density advantage in the SLI group. Research has suggested that children with smaller vocabularies learn words from dense neighborhoods more readily than words from sparse neighborhoods, perhaps because high-density words are produced with longer durations that facilitate word learning (Munson & Solomon, 2004). Stokes (2010) found that toddlers with smaller vocabularies had lexicons with more high-density words, whereas toddlers with the largest vocabularies had lexicons

with more low-density words. Perhaps children with SLI, who have smaller vocabularies than their peers, benefit from the longer durations of high-density words.

Naming

Naming required children to recall and produce a word form after hearing and seeing its referent. We found significant main effects for phonotactic probability, neighborhood density, and time, with a significant Time $\times$ Group interaction (see Figure 3). Post hoc analyses showed a low-density advantage for the AM group and a high phonotactic probability advantage for the VM group, but no effect for the SLI group. Figure 2 provides a good illustration of the Time $\times$ Group interaction. The AM group naming accuracy started close to the VM and SLI groups after 15 presentations of each word, but their learning slope was steeper overall, and by the last naming probe they outperformed both other groups, except for high-probability-high-density words, where the VM group's performance matched the AM group's.

In general, naming performance for the VM and SLI groups was quite similar. We hypothesize that this may be due, in part, to their extant vocabulary. High density may not convey an advantage for these groups because they do not have as many words stored in their lexicon. This means that fewer words compete for retrieval during naming.

Why the high phonotactic probability advantage for the VM group? Given their high phonotactic probability advantage for referent identification, we expect that these words were stored with better specification than other word types, which would aid successful retrieval and production. Why no advantage for the SLI group? On the basis of referent identification results, they did not appear to benefit from high phonotactic probability as did the AM and VM groups and likely did not create and store well-specified word-form representations for any word type. In addition, as discussed above, they may not have benefited from high density because of their smaller lexicons.

As with referent identification, our naming results are not directly comparable to those of earlier studies with preschoolers with TD because both phonotactic probability and neighborhood density have not been manipulated in studies with children, but they are directly comparable to the results of Storkel et al.'s (2006) study with adults that used the same words and partial plus completely correct productions as the dependent variable in the analyses. Unlike any of our groups, adults showed a low phonotactic probability advantage. This was inconsistent with previous naming results in word-learning studies of preschoolers that showed a high probability advantage with high-density words (Storkel, 2001, 2003), but consistent with studies with preschoolers showing a low probability advantage with low-density words (Gray & Brinkley, 2011; Gray, Brinkley, & Svetina, 2012). The difference is that these earlier studies did not simultaneously manipulate phonotactic probability and neighborhood density; therefore, it is not surprising that results differed.

Storkel et al. (2006) hypothesized that the low-probability advantage they found for adults may have occurred because low-probability words stand out more in relation to words stored in the lexicon and may therefore trigger early word learning. Our study provided a good test of this hypothesis in children because we assessed naming after more exposures than did

Storkel et al., but we found no interaction, indicating a low-probability advantage early in the word-learning process and a high-probability advantage later after more exposures. Instead, it appears that for the AM and VM groups, naming performance was consistently low for low-probability-low-density words.

Adults also showed a high-density advantage for naming that we did not find for any preschool group. The AM group showed a low-density advantage, which is consistent with the hypothesis that words from low-density neighborhoods should be easier to produce because there is less competition from neighbors. We also found a low-probability-low-density advantage in earlier studies with preschoolers, but again we did not test high-density words in those studies (Gray & Brinkley, 2011; Gray, Brinkley, & Svetina, 2012).

Clearly, factors influencing naming may change in the developmental course from preschool to adulthood, which are the two ends of the word-learning spectrum for which we have data. Further studies with elementary-age students will shed light on the possible shift in factors that affect naming as children age and their vocabularies grow.

Additional Factors Affecting Word Learning

In the introduction, we advocated for a cohesive model (triggering → configuration + engagement) that encompasses and defines each stage of word learning. We proposed that researchers consider the impact of four important factors on each stage of word learning: the abilities and experience people bring to the task (participant characteristics), the characteristics of the words to be learned, the characteristics of the referents, and the learning context. By doing this, researchers and clinicians can move toward the ultimate goal of understanding word learning and how it might be improved for children with language impairment.

The three participant groups in our study brought different abilities and experience to the word-learning task. The AM and SLI groups did not differ in age or in mother's education level, which might help equate for word-learning experience. We matched the SLI and VM groups on expressive vocabulary raw scores as one method, albeit an imperfect one, of equating their lexicons. However, raw scores on the CASL Antonyms subtest showed that the AM group named more opposites than the VM group and the VM group more than the SLI group. Therefore, it is likely that the AM group had a larger extant vocabulary than the VM group and the VM group a larger extant vocabulary than the SLI group.

The 16 nonwords used in this study were short CVC sequences. The systematic manipulation of phonotactic probability and neighborhood density requires short words because the longer the word, the fewer lexical neighbors and the lower the phonotactic probability. Short words, though, also reduce working memory load, which could potentially mitigate problems experienced by children who have poor short-term phonological memory when learning longer words. Nonword repetition results have consistently shown that children with TD score higher than children with SLI on nonword repetition tasks, and between-group effect sizes increase with word length (Graf Estes, Evans, & Else-Quest, 2007). We need studies that examine the effect of word length as well as phonotactic probability and neighborhood density.

Referent choices also matter in word-learning studies. For example, research has shown that learning a second name for a referent (e.g., *Dalmation* for dog) is more difficult than learning an initial name for a novel object (Gray & Brinkley, 2011; Gray, Brinkley & Svetina, 2012). Presumably this is because the stored word form competes for retrieval with the new word form, inhibiting storage and retrieval of the new word. In this study, we selected colored clip-art referents unfamiliar to children. They were not free of any semantic associations, but by counterbalancing referent sets across word types we had reasonable assurance that this would not affect the word-form results that we were most interested in. Researchers must attend to referent characteristics when they design word-learning studies, and studies that examine the effects of both word and referent characteristics in the same groups of children are needed.

The learning context of this study was designed to evaluate trial-by-trial learning for referent identification across many exposures. In real life, it would take months to provide this many exposures and most certainly the environmental factors affecting learning would vary tremendously from sitting in front of a computer. Therefore, we need to test hypotheses about the impact of learner, word, and referent characteristics gained in the lab under controlled conditions in the real world to determine how well findings generalize.

Summary

Key findings accruing from this study are that during the configuration stage of word learning, the word characteristics of phonotactic probability and neighborhood density affect older and younger preschoolers with TD differently and affect preschoolers with SLI differently than their age-matched and vocabulary-matched peers. For referent identification, preschoolers with TD benefited from high phonotactic probability and the younger group also benefited from low neighborhood density. In contrast, the SLI group benefited only from high neighborhood density. We proposed that this was due to the SLI group's difficulty in creating and storing well-specified sublexical representations that are most affected by phonotactic probability and instead creating and storing more holistic representations that are most affected by neighborhood density. For referent naming, older preschoolers with TD benefited most from low-density words, younger preschoolers with TD benefited most from high phonotactic probability words, and the SLI group showed no advantage. We hypothesized that these findings were primarily due to the smaller lexicons of the VM and SLI groups and the SLI group's inability to capitalize on phonotactic probability to support sublexical processing.

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Figure 1.

Referent identification learning functions (top) and percentage of phonemes correct for naming (bottom) by group for each word type. AM = age-matched group; VM = vocabulary-matched group; SLI = specific language impairment group.

Figure 2. Referent identification learning functions (top) and percentage of phonemes correct for naming (bottom) by word type for each group. Note that these data are the same as those presented in Figure 1 but are reorganized to highlight between-group differences for each word type. AM = age-matched group; VM = vocabulary-matched group; SLI = specific language impairment group.

Figure 3.

Estimated marginal means for percentage of phonemes correct at each time point by group. Error bars represent standard errors. AM = age-matched group; VM = vocabulary-matched group; SLI = specific language impairment group.

Table 1.

Summary of results of studies investigating effects of phonotactic probability and neighborhood density on word-learning configuration.

Study	No. of exposures	Referent characteristics	Word type			
			High probability–high density	High probability–low density	Low probability–high density	Low probability–low density
Referent Identification						
Preschoolers with TD						
Storkel (2001)	7	Familiar objects (pictures)	✓	—	—	
Storkel & Lee (2011) Experiment 1	12–72	Black line drawings of nonobjects	—		—	✓
Storkel & Lee (2011) Experiment 2,	12–72	Black line drawings of nonobjects		✓ ^a	—	—
Preschoolers with TD and with SLI						
Gray & Brinkley (2011)	105	Unfamiliar or familiar objects	—		—	✓
Gray, Brinkley, & Svetina (2012)	132	Unfamiliar or familiar objects	—	=	—	=
School-age children with TD						
Storkel & Rogers (2000)	5	Familiar objects (pictures)	✓ ^b	—	—	
Form Identification						
Preschoolers with TD						
Storkel (2001)	7	Familiar objects (pictures)	✓	—	—	
Naming						
Preschoolers with TD						
Storkel (2001)	7	Familiar objects (pictures)	✓	—	—	
Storkel (2003)	7	Unfamiliar actions (pictures)	✓	—	—	
Gray & Brinkley (2011)	105	Unfamiliar or familiar (pictures)	—		—	✓
Gray, Brinkley, & Svetina (2012)	132	Unfamiliar or familiar objects	—		—	✓
Adults with TD						
Storkel et al. (2006), ^c main effect of phonotactic probability	7	Black line drawings of nonobjects			✓	✓
Storkel et al. (2006), main effect of neighborhood density	7	Black line drawings of nonobjects	✓		✓	

Note. Check mark indicates statistically significant advantage over condition in unchecked column; dashes indicate not assessed; equals sign indicates no statistically significant differences. TD = typical language development.

^aStorkel and Lee (2011) Experiment 2 compared neighborhood density while holding phonotactic probability constant using words with medium rather than high or low phonotactic probability. Result plotted is for accuracy immediately after training.

^bStorkel and Rogers (2000) found a high probability-high density advantage for 10- and 13-year-olds but no effect for 7-year-olds.

^cStorkel et al. (2006) found a low phonotactic probability advantage when they combined scores for completely and partially correct responses but no advantage for completely correct responses.

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Table 2.

Participant description information, including summary of test results for the specific language impairment (SLI), age-matched (AM), and vocabulary-matched (VM) groups.

Measure	SLI (<i>n</i> = 48)		AM (<i>n</i> = 44)		VM (<i>n</i> = 39)		<i>F</i>	<i>df</i>	<i>p</i>
	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>			
Age	56.96 ^c	5.77	55.89 ^b	6.08	47.67 ^{b,c}	7.94	24.64	2, 128	.000
Mother's education	14.65	1.71	14.91	1.84	15.49	1.79	2.47	2, 128	.089
K-ABC	101.48 ^a	12.79	110.93	12.19	107.13	15.20	5.84	2, 128	.004
PPVT-III	94.27 ^{a,c}	10.26	104.66 ^a	11.35	101.13 ^c	16.59	7.87	2, 128	.001
EVT									
SS	92.81 ^{a,c}	7.19	108.5 ^a	12.08	106.49 ^c	9.81	34.65	2, 128	.000
RS	42.15 ^a	6.13	52.19 ^{a,b}	9.79	44.72 ^b	7.80	18.92	2, 127	.000
BBTOP WI	77.48 ^{a,c}	10.02	99.61 ^a	10.12	99.23 ^c	11.26	67.30	2, 128	.000
CASL									
SC	89.83 ^{a,c}	12.06	106.43 ^a	12.15	104.74 ^c	10.26	28.53	2, 128	.000
PC	90.88 ^a	17.26	103.30 ^a	19.95	100.36	20.91	5.21	2, 128	.007
A	8.15 ^{a,b}	3.68	12.26 ^{a,b}	3.32	9.36 ^b	3.99	14.81	2, 127	.000
SPELT-P2	72.10 ^{a,c}	11.39	109.05 ^a	7.71	104.90 ^c	10.75	184.40	2, 128	.000
NWR PPC	54.40 ^a	15.90	72.36 ^{a,b}	16.96	62.59 ^b	17.13	12.97	2, 125	.000

Note. Age is reported in months. Values are standard scores. The normative mean was 100 (SD =15). K-ABC = Nonverbal scale of the Kaufman Assessment Battery for Children, Second Edition (Kaufman & Kaufman, 2004); PPVT-III = Peabody Picture Vocabulary Test—3rd Edition (Dunn & Dunn, 1997); EVT-SS = standard score on the Expressive Vocabulary Test (Williams, 1997); EVT-RS = raw score on the Expressive Vocabulary Test (Williams, 1997); BBTOP = Bernthal-Bankson Test of Phonology (Bankson & Bernthal, 1990); WI = Word Inventory subtest; CASL = Comprehensive Assessment of Spoken Language (Carrow-Woolfolk, 1999); SC = Sentence Completion subtest; PC = Paragraph Comprehension subtest; A = Antonyms Subtest raw scores; SPELT-P2 = Structured Photographic Expressive Language Test—Preschool 2 (Dawson et al., 2005); NWR = nonword repetition, measured in percentage of phonemes correct (PPC).

^aDifferences in means between SLI and AM groups indicated are significant at the .05 level.

^bDifferences in means between AM and VM groups indicated are significant at the .05 level.

^cDifferences in means between SLI and VM groups indicated are significant at the .05 level.

Table 3.

Nonwords.

<u>High phonotactic probability</u>		<u>Low phonotactic probability</u>	
High density	Low density	High density	Low density
pim	han	jerm	faog
joon	nep	ferg	jAd
mek	jrb	hif	waf
wæd	parb	naut	møg

Note. Nonwords from Storkel et al. (2006).

Table 4.

Summary of repeated measures analyses of variance for referent identification.

Source	<i>F</i>	<i>df</i>	<i>p</i>	η^2
Main effects				
Phonotactic probability	26.41	1, 110	< .001	.19
Neighborhood density	2.00	1, 110	.160	.02
Group	14.36	2, 110	< .001	.21
Phonotactic Probability $\times$ Group	13.67	2, 110	< .001	.20
Neighborhood Density $\times$ Group	3.37	2, 110	.038	.06
Phonotactic Probability $\times$ Neighborhood Density	8.50	1, 110	.004	.07
Phonotactic Probability $\times$ Neighborhood Density $\times$ Group	2.52	2, 100	.085	.04
Post hoc effects, by group				
AM				
Phonotactic probability	5.76	1, 38	.021	.13
Neighborhood density	0.00	1, 38	.962	.00
Phonotactic Probability $\times$ Neighborhood Density	0.99	1, 38	.324	.03
VM				
Phonotactic probability	35.19	1, 32	< .001	.52
Neighborhood density	0.12	1, 32	.732	.00
Phonotactic Probability $\times$ Neighborhood Density	6.73	1, 32	.014	.17
SLI				
Phonotactic probability	0.05	1, 40	.822	.00
Neighborhood density	7.72	1, 40	.008	.16
Phonotactic Probability $\times$ Neighborhood Density	0.73	1, 40	.40	.02

Note. AM = age-matched group; VM = vocabulary-matched group; SLI = specific language impairment group.

Table 5.

Summary of repeated measures analyses of variance for naming.

Source	<i>F</i>	<i>df</i>	<i>p</i>	η^2
Main effects				
Phonotactic probability	10.05	1, 122	.002	.08
Neighborhood density	3.95	1, 122	.049	.03
Group	2.12	2, 122	.124	.03
Time	99.31	3, 366	< .001	.45
Phonotactic Probability $\times$ Group	1.30	2, 122	.275	.02
Neighborhood Density $\times$ Group	0.91	2, 122	.404	.01
Time $\times$ Group	4.88	6, 366	.003	.05
Phonotactic Probability $\times$ Neighborhood Density	1.63	1, 122	.204	.01
Phonotactic Probability $\times$ Time	0.15	3, 366	.927	.00
Neighborhood Density $\times$ Time	0.29	3, 366	.830	.00
Phonotactic Probability $\times$ Neighborhood Density $\times$ Group	0.20	2, 122	.822	.00
Phonotactic Probability $\times$ Time $\times$ Group	1.62	6, 366	.477	.01
Neighborhood Density $\times$ Time $\times$ Group	0.12	6, 366	.582	.01
Phonotactic Probability $\times$ Neighborhood Density $\times$ Time	0.01	3, 366	.813	.00
Phonotactic Probability $\times$ Neighborhood Density $\times$ Time $\times$ Group	1.04	6, 366	.282	.02
Post hoc effects, by group				
AM				
Phonotactic probability	3.17	1, 43	.082	.07
Neighborhood density	6.00	1, 43	.018	.12
Time	54.85	3, 129	< .001	.56
Phonotactic Probability $\times$ Neighborhood Density	0.55	1, 43	.464	.01
Phonotactic Probability $\times$ Time	0.36	3, 129	.782	.00
Neighborhood Density $\times$ Time	0.24	3, 129	.867	.01
Phonotactic Probability $\times$ Neighborhood Density $\times$ Time	1.16	3, 129	.328	.03
VM				
Phonotactic probability	8.76	1, 35	.005	.20
Neighborhood density	0.17	1, 35	.682	.00
Time	37.27	3, 105	< .001	.64
Phonotactic Probability $\times$ Neighborhood Density	1.34	1, 35	.255	.04
Phonotactic Probability $\times$ Time	1.83	3, 33	.05	.11
Neighborhood Density $\times$ Time	1.35	3, 105	.262	.00
Phonotactic Probability $\times$ Neighborhood Density $\times$ Time	0.819	3, 105	.486	.03
SLI				
Phonotactic probability	0.51	1, 44	.479	.01
Neighborhood density	0.61	1, 44	.440	.01
Time	15.78	3, 132	< .001	.26
Phonotactic Probability $\times$ Neighborhood Density	0.09	3, 132	.762	.01
Phonotactic Probability $\times$ Time	0.15	3, 132	.930	.01

Source	<i>F</i>	<i>df</i>	<i>p</i>	η^2
Neighborhood Density $\times$ Time	0.29	3, 132	.832	.01
Phonotactic Probability $\times$ Neighborhood Density $\times$ Time	0.82	3, 132	.485	.02

Note. AM = age-matched group; VM = vocabulary-matched group; SLI = specific language impairment group.