Lexical and Phonological Organization in Children: Evidence From Repetition Tasks

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This study examined the structure of children's mental lexicons through performance on 2 short experimental tasks, 1 in which children repeated familiar monosyllabic real words varying in neighborhood density and 1 in which they repeated CVC nonwords varying in phonotactic probability. Two groups of typically developing children with mean ages of 4;3 (years;months; *n* = 16) and 7;2 (*n* = 15) participated. In the group of younger children, offset-to-onset response latencies were not systematically affected by lexicality, phonotactic probability, or neighborhood density. Onset-to-onset latencies showed an effect of phonotactic probability on nonword repetition. Children in the older group repeated high-density real words with longer latencies than low-density real words. They also repeated high-probability nonwords with shorter latencies than low-probability nonwords. This was true for both the onset-to-onset and offset-to-onset repetition latencies. Children in both age groups repeated vowels embedded in high-probability nonwords with shorter durations than vowels embedded in low-probability nonwords. These findings suggest that lexical competition and phonological facilitation emerge in development and that the rate of development is different for different dependent measures.

KEY WORDS: phonological neighborhood density, phonotactic probability, nonword repetition, real-word repetition, children

Recent psycholinguistic investigations have converged on two conclusions regarding lexical and phonological representations in memory. The first is that the lexicon is organized systematically, based on the similarity of individual lexical items (e.g., Pisoni, Nusbaum, Luce, & Slowiaczek, 1985). This lexical organization is highly dimensional: Lexical items are organized in terms of semantic similarity, morphosyntactic similarity, and phonological similarity, among others. The second notion is that phonological representations in memory comprise multiple, parallel levels of structure. That is, a representation of a monosyllabic CVC word comprises a representation of the entire word shape, as well as its individual phonemes and diphone sequences.

The belief that the lexical items are organized in terms of phonological similarity has arisen from studies examining the influence of phonological neighborhood density on lexical processing. *Neighborhood density* refers to the number of real words that can be created by adding, deleting, or changing one sound in a real-word target (Pisoni et al., 1985). Words can range in neighborhood density from high (e.g., *pill*, which has 32 neighbors, including *pit*, *spill*, *ill*, *will*, and *pole*) to low (e.g., *choice*, which has 3 neighbors, including *voice* and *chase*). Across a range of experimental methodologies, it has been shown that words that reside in high-density neighborhoods are processed differently than words that reside in low-density neighborhoods. Items in high-density neighborhoods are less audible than those in low-density neighborhoods (Dirks, Takayanagi, & Moshfegh, 2001). Pictures whose names reside in high-density neighborhoods are named more quickly than those in low-density neighborhoods (Vitevitch, 2002). Words with high neighborhood densities are produced with more expanded acoustic vowel spaces than words with low neighborhood densities (Munson & Solomon, 2004; Wright, 2004). Finally, words' neighborhood density affects the rate of naming errors in typically developing children and children with word-finding problems (Newman & German, 2002).

Recently, Vitevitch and Luce (1998, 1999) examined the influence of neighborhood density on the processing of real words. They found that real words that were high in neighborhood density were repeated more slowly than words that were low in neighborhood density. In the same studies, Vitevitch and Luce examined the influence of manipulations of phonotactic probability, a parameter that is very similar to neighborhood density, on the processing of nonword sequences. *Phonotactic probability* is a measure of the frequency of occurrence of the sequences of sounds making up a word or nonword (Frisch, Large, & Pisoni, 2000; Vitevitch & Luce, 1998, 1999). For example, the nonword [dʒoʊm] has a lower phonotactic probability than the nonword [peɪk], as the sequences [dʒoʊ] and [oʊm] occur in fewer real English words than the sequences [peɪ] and [eɪk]. In contrast to neighborhood density, phonotactic probability has a facilitatory effect on the processing of nonwords. Nonwords that are high in phonotactic probability are repeated more quickly than those that are low in phonotactic probability. The asymmetric effects of neighborhood density and phonotactic probability on real-word and nonword repetition led Vitevitch and Luce to posit that phonological representations in memory comprise at least two levels of representation. At the lexical level, items are subject to competition. Real words that are phonologically similar to other real words are more difficult to process than those that are not. At the phonological level, items are subject to facilitation. Nonwords that are phonologically similar to real words are easier to process than those that are not.

Other studies have shown that phonotactic probability influences performance on a variety of tasks. For example, children learn high-probability nonwords more quickly than low-probability nonwords (Storkel, 2001). Frisch et al. (2000) found that individuals' immediate and long-term memory for high-probability nonwords is more accurate than that for low-probability nonwords. Pitt and McQueen (1998) found that listeners perceive acoustically ambiguous phoneme sequences to be members of high-probability sequences rather than low-probability ones. Hay, Pierrehumbert, and Beckman (2004) found that listeners misperceive low-probability phoneme sequences as high-probability sequences more often than the reverse. Finally, Munson (2001) found that both adults and children repeat high-probability phoneme sequences with shorter and less variable durations than low-probability sequences.

Phonotactic probability and neighborhood density are correlated. A word or nonword with a high phonotactic probability will always be high in neighborhood density. A word or nonword that is high in neighborhood density may or may not be high in phonotactic probability. The real word *cat* and the nonword [kæk] are high in both phonotactic probability (because the component diphone sequences [kæ], [æk], and [æt] occur in many other real words) and neighborhood density (because of their similarity to such words as *keep*, *cap*, *kick*, *sack*, and *cake*). In contrast, the real word *cook* and the nonword [koɪk] are low in phonotactic probability (because the component sequences [kʊ], [koɪ], [ʊk], and [oɪk] occur in relatively few real English words) but high in neighborhood density (because of their similarity to such real words as *coy*, *look*, *cake*, *coke*, and *kick*). Phonotactic probability can be calculated for real words, and neighborhood density can be calculated for nonwords. Indeed, at least two recent investigations have examined these variables separately. Bailey and Hahn (2001) found that neighborhood density and phonotactic probability predicted variance in metalinguistic judgments of wordlikeness of nonword sequences independently, although neighborhood density measures predicted more variance than phonotactic probability. Luce and Large (2001) examined the influence of neighborhood density and phonotactic probability on speeded same–different judgments of real words and nonwords. They found independent facilitative effects of phonotactic probability and inhibitory effects of neighborhood density for reaction times to real-word stimuli.

The subject of this investigation is the development of the lexical and phonological levels of representation in typically developing children. Previous research has found that both levels of representation are subject to development. Munson (2001) examined development of the phonological level of representation. Munson found that young children repeated nonword-embedded diphone sequences occurring in few or no lexical items (i.e., /mk/, /ʃp/) less accurately and with longer and more variable durations than diphone sequences occurring in many words (i.e., /mp/, /st/). Older children and adults demonstrated a smaller effect. Edwards, Beckman, and Munson (2004) and Munson, Edwards, and Beckman (2005) replicated these findings with a larger age range of participants and a larger set of diphone sequences. These results suggest that children do not have access to robustly abstracted units at the phonological level of representation. That is, young children's nonword repetition is heavily biased by their knowledge of sound sequences at the lexical level of representation. When these children are required to utter unfamiliar sequences of phonemes, they do so inaccurately and with poorer speech motor control, as they cannot use a motor scheme from a known lexical item or a robustly abstracted phonological representation to do so. In addition, Edwards et al. and Munson et al. found that an estimate of lexicon size predicted the difference in accuracy between children's production of high- and low-frequency diphone sequences. These investigators interpreted this as evidence for a relationship between lexical development and the development of phonological representations. As children acquire more lexical items, they begin to develop robust representations for phonological units, such as phonemes and phoneme sequences. These phonological units can be combined into novel sequences in nonsense words fluently, accurately, and consistently.

Other investigators have studied the development of the lexical level of representation. Computational studies of children's lexicons have shown that neighborhood density increases with development (Charles-Luce & Luce, 1990, 1995; Dollaghan, 1994; Logan, 1992). Children's early lexicons contain fewer similar sounding words than do those of adults. Consequently, children are less likely than adults to know a cohort of similar sounding words that would constitute a high-density phonological neighborhood. As children learn more words, the number of words in dense neighborhoods increases. Storkel (2002) provided empirical evidence that lexical neighborhood structure influences children's phonological processing. Storkel measured preschool children's tacit perceptual similarity judgments for CVC words in sparse neighborhoods and in dense neighborhoods using a standard-word/test-word comparison paradigm. She found that children's tacit similarity judgments for words in dense neighborhoods were sensitive to the similarity of the phonemes in both the CV and the VC sequences. Tacit similarity judgments for words in sparse neighborhoods were based on the similarity of the phonemes in the CV sequence but on similarity of the manner of articulation of sounds in the VC sequence. This result suggests that children's phonological representations of words that reside in high-density neighborhoods are more detailed than representations of words in low-density neighborhoods. Lexical factors have been shown to influence children's performance on other experimental measures of nonword repetition and spoken word recognition (Garlock, Walley, & Metsala, 2001; Metsala, 1997, 1999), providing additional evidence that lexical development influences phonological development.

This article builds on past research by using two repetition tasks to measure competition and facilitation at the lexical and phonological levels of representation in preschool children and early-elementary-school-age children. In one task, children repeated real words varying in neighborhood density; in the other task, children repeated nonsense words varying in phonotactic probability. As in Vitevitch and Luce (1998), we assumed the influence of phonotactic probability on nonword repetition latency could be used to measure the organization of items at the phonological level of representation. Similarly, we used the influence of neighborhood density on real-word repetition latency to measure the organization of items at the lexical level of representation.

This study differs from previous studies in a number of ways. First, no previous research has examined children's processing of real words varying in neighborhood density and nonwords varying in phonotactic probability in the same experiment. The key evidence arguing for the existence of lexical competition and phonological facilitation in adults has come from studies comparing the effects of probability and density on real-word and nonword repetition. To date, no comparable study has been completed with children. This study examines real-word and nonword repetition in preschool children and early-elementary-school-age children, both to determine whether lexical competition and phonological facilitation effects are present in children and to assess whether the magnitude and direction of these effects change throughout development.

Second, this study differs from previous research on children in the dependent measures that are examined. Previous research on phonotactic probability and neighborhood density in children has used measures of spoken word recognition accuracy (i.e., Garlock et al., 2001); nonword repetition accuracy (i.e., Edwards et al., 2004; Munson et al., 2005); nonword repetition duration (Munson, 2001); and perceptual similarity judgments (Storkel, 2002). In this study, two measures are made from children's correct responses. The first is response latency. Previous studies on adults have shown that nonwords are repeated with longer latencies than real words; that real words that are high in neighborhood density are repeated with longer latencies than those low in neighborhood density; and that nonwords that are low in phonotactic probability are repeated with longer response latencies than those that are high in phonotactic probability. These differences in response latencies have been used to argue for the existence of lexical competition and phonological facilitation. In this study, we examine whether children's responses show the same patterns as adults' responses have in previous research. Specifically, we examine whether children have longer response latencies for real words than for nonwords, whether they show lexical competition effects in real-word repetition tasks, and whether they show phonological facilitation in nonword tasks. We also examine whether the influences of lexicality and probability change with age.

The second dependent measure examined in this experiment is response duration. Specifically, we examine whether phonotactic probability and neighborhood density influence children's production of vowels embedded in real words and nonwords and whether this changes as a function of age. Previous research has shown that this segment duration is influenced by phonotactic probability in nonwords (Edwards et al., 2004; Munson, 2001) and neighborhood density in real words (Munson & Solomon, 2004).

The predictions for this study are presented in Table 1. For latency, we predict that younger children will demonstrate smaller effects of lexicality than older children, as younger children have less experience in perceiving and producing real words than older children. We also predict that lexical competition effects will be smaller for younger children than for older children, as the smaller vocabularies of the younger children make it less likely that their lexicons will contain high-density neighborhoods. We predict that phonological facilitation effects will be present in both groups of children but that they will be larger in the older group of children. Previous research has shown phonological facilitation effects to be present in production at an early age (e.g., Munson, 2001); hence, we predict that they are present in processing as well. However, we predict that they will be stronger in older children, as these children's robustly abstracted representations of phonemes will facilitate their ability to use high-probability phoneme sequences to process nonwords efficiently.

For duration, we predict that both groups of children will repeat vowels in high-probability nonwords with shorter durations than for those in low-probability nonwords. Following Munson (2001), we reason that children will experience difficulty generalizing correct vowel production to nonword-embedded low-probability phoneme sequences and that this will be reflected by longer vowel durations in those tokens. Finally, we predict that the effect of probability on duration will be larger for younger children than for older children, in keeping with previous studies on phonotactic probability and speech-sound duration (Edwards et al., 2004; Munson, 2001; Munson et al., 2005). The predictions regarding real words are similar: Children will produce vowels embedded in high-density real words with shorter durations than low-density ones, and this effect will attenuate with age. These hypotheses are tested through a study of the latency and duration of children's real-word and nonword repetitions.

Method

Participants

Thirty-one children participated in the experiment. The younger group (n = 16) had a mean age of 4;3 (years;months; SD = 10 months). The older group (n = 15) had a mean age of 7;2 (SD = 9 months). Children completed the Goldman–Fristoe Test of Articulation–2 (GFTA-2; Goldman & Fristoe, 2000) and the Expressive Vocabulary Test (EVT; Williams, 1997). No child received a standard score of less than 85 on the EVT or a GFTA-2 percentile rank less than 17, which would indicate performance greater than 1 SD below the mean of the normative sample of children in their age range. None

Table 1. Experimental predictions.

	Experimental factor			
Dependent measure	**Lexicality**	**Probability/density**	**Age**	**Interaction**
Response latency	Real words will be repeated with shorter latencies than nonwords.	High-density real words will be repeated with longer latencies than low-density real words; high-probability nonwords will be repeated with shorter latencies than low-probability nonwords.	Younger children will repeat items with longer latencies than older children.	The effects of lexicality and probability/density will be larger for the older children.
Response duration	—	High-probability and high-density items will be repeated with shorter durations than low-probability/low-density ones.	Younger children will repeat items with longer durations than older children.	The effects of lexicality and probability/density will be larger for the older children.

Note. There were no predictions for lexicality in relation to response duration.

Table 2. Real-word and nonword stimuli.

Nonword		Real word	
High probability	**Low probability**	**Low density**	**High density**
bis	giv	stop	cap
dis	jiθ	sit	cut
seɪd	tʃeɪdʒ	fish	kick
teɪn	veɪz	good	bed
dɑp	sɑtʃ	white	fight
rɑp	wɑf	cow	grow
hoʊk	voʊtʃ	dance	hand
noʊl	dʒoʊm	give	pink
tup	wuk	hurt	hot
bus	duθ	friend	thumb
wɪd	zɪs	home	bone
pɪp	ʃɪf	foot	cook
hɛs	kɛθ	catch	bath
dɛs	kɛf	gray	high
mæk	tʃætʃ	food	dad
bæp	fæʃ	time	ride

Note. Stimuli used in the onset-to-onset latency analysis are underlined.

of the children had a history of speech, language, or hearing impairment, or chronic otitis media; and all were progressing normally through school, as reported by parents. All children were native, monolingual speakers of English. Children were rewarded with stickers for their participation.

The younger children had a mean EVT standard score of 113 (SD = 12); the older children had a mean score of 109 (SD = 11). This difference was not significant, $F(1, 29) < 1$, $p > .05$. As expected, raw scores on this test did differ significantly, $F(1, 29) = 30.5$, $p < .01$. The younger children had an average raw score of 52 items (SD = 11); the older group had an average raw score of 77 items (SD = 12). The younger children had a mean GFTA-2 percentile ranking of 66 (SD = 32); the mean score for the older children was 52 (SD = 32). This difference was not significant, $F(1, 29) = 2.2$, $p > .05$. Children passed an air-conduction hearing screening at 20 dB HL bilaterally at 0.5, 1, 2, and 4 kHz (American National Standards Institute, 1989).

Children's phonetic repertoires were calculated based on their performance on the GFTA-2. For the purposes of assessing phonetic inventories, all of the stimulus words on the GFTA-2 were phonetically transcribed in their entirety, rather than just the target phonemes. Measures of overall accuracy on the GFTA (as measured for both target and nontarget consonant sounds) found that the younger children demonstrated more errors than the older children (M = 15, SD = 20, for the younger children; M = 3, SD = 3, for the older children). Errors in both groups were not normally distributed; hence, a nonparametric Wilcoxon test was used to examine group differences. This test indicated that the group difference was significant ($T = 160$, $z = –3.1$, $p < .01$). Children had between zero and five phonemes consistently in error across word positions. Children's consistent residual errors were either place-of-articulation substitutions (i.e., f/θ) or /r/ distortions (i.e., age-appropriate misarticulations of /r/ that were perceptually distinct from /w/). No children evidenced consistent deletion errors or manner-of-articulation substitutions, with the exception of 1 child who demonstrated a b/v substitution that was inconsistent across words and word positions.

Stimuli

The real words used in this experiment were a subset of the words from the Lexical Neighborhood Test (Kirk, Pisoni, & Osberger, 1995). The high- and low-density words were chosen to be as phonetically similar as possible, so that performance differences between the two lists could not be attributed to the phonetic characteristics of the stimuli. The real words are presented in Table 2. Each low-density real word was matched with a high-density real word for syllable structure and approximate intrinsic duration of the vowel. Multiple chi-squared tests showed that the two lists did not differ significantly in the place, manner, or voicing of the consonants comprising the real-word stimuli. The neighborhood size of the words constituting the two lists was calculated based on the Hoosier mental lexicon (Pisoni et al., 1985). The mean number of neighbors for the high-density words was 19 (SD = 6). The mean number of neighbors for the low-density words was 12 (SD = 6). The two lists differed significantly in this variable, $F(1, 30) = 8.3$, $p < .01$, partial $\eta^2 = .21$. In addition, the log frequency of the words constituting the two lists was measured. The average log frequency for the high-density words was 4.1 (SD = 1.1). The average log frequency for the low-density words was 4.9 (SD = 1.1). This difference approached significance, $F(1, 30) = 3.8$, $p = .06$, partial $\eta^2 = .11$. Phonotactic probability for the real-word stimuli was measured using the method described in Frisch et al. (2000). The two lists did not differ in this variable, $F(1, 30) < 1$, $p > .05$. The average phonotactic probability for the high-density words was –10.4 (SD = 2.2). The average for the low-density words was –11.1 (SD = 2.6). Previous research had shown that age of acquisition (AoA) mediates the influence of neighborhood density on children's spoken word recognition (Garlock et al., 2001). AoA of the high- and low-density words was measured using the values in Bird, Franklin, and Howard (2001). This corpus does not report AoA values for all of the words in this study. It does, however, provide AoA estimates for 13 of the low-density words and

7 of the high-density words. The two lists did not differ (T = 131.5, z = –0.400, p > .05). The mean AoA for the high-density words was 245 (SD = 36); that for the low-density words was 240 (SD = 41).

As in previous research (Edwards et al., 2004; Munson, 2001; Munson et al., 2005), high- and low-probability nonwords were created based on the frequency of diphone sequences in the Moe, Hopkins, and Rush (1982) database of the 6,366 most frequent words in the speech of typically developing first-grade children. This database was created by making an online version of the words from Moe et al.'s (1982) database and then taking the words' phonetic transcriptions from the Carnegie Mellon University Pronouncing Dictionary (http://www.speech.cs.cmu.edu/cgi-bin/cmudict). The Moe et al. database contains a mix of both spontaneous speech and structured conversations on familiar topics. The nonword stimuli are presented in Table 2. All of the nonsense words had a CVC structure. The high- and low-probability nonwords were balanced for vowel quality. Multiple chi-square tests indicated that the lists did not differ significantly in the place, manner, and voicing of the consonants constituting the nonwords. The phonotactic probability of each stimulus was calculated using the method in Frisch et al. (2000), as the sum of the log-transformed probabilities of the diphone sequences constituting the nonwords. The mean phonotactic probability for the low-frequency sequences was –11.4 (SD = 1.7). The mean phonotactic probability for the high-frequency nonwords was –8.3 (SD = 1.0). The two lists differed significantly in phonotactic probability, $F(1, 30) = 40.2, p < .01$, partial $\eta^2 = .58$. The two lists also differed in their neighborhood density, based on their similarity to words in the Hoosier mental lexicon. The average number of neighbors for the high-probability words was 16 (SD = 3). The average number of neighbors for the low-probability words was 6 (SD = 2.4).

A phonetically trained adult female student in speech-language pathology recorded the real-word and nonword production prompts. These were recorded using an AKG C420 head-mounted microphone attached to a Roland VS-890 digital workstation through a Rolls phantom power source. A 44.1-kHz sampling rate and 16-bit quantization were used. The larger digital file was divided into individual files containing each word. The peak amplitude of each word was normalized. Five repetitions of each word were recorded. A group of five adults listened to all of the tokens in a sound-treated booth, played from a pair of high-quality speakers at a level of approximately 60 dB SPL. The real-word tokens used in the experiment were identified correctly by at least four of these listeners, and most of the stimuli were identified correctly by all five listeners. The nonword tokens used in the experiment were repeated correctly by at least four of these listeners, and most were repeated correctly by all five. By choosing items that were highly intelligible to normal hearing listeners at a presentation level slightly lower than that used in the experiment, we hoped to minimize the chance that the participants would misperceive the items during the experiment.

Whole-word durations and vowel durations were measured for the stimuli. Vowel durations were measured from digitized waveforms, using standard criteria for segmentation. Two, two-factor between-subjects analyses of variance (ANOVAs) examined whether the stimulus duration and stimulus vowel duration differed as a function of lexicality and probability. Vowel durations were not found to differ as a function of lexicality, probability, or the interaction between them. In contrast, the entire stimuli differed as a function of lexicality, $F(1, 60) = 11, p < .01$: Real-word stimuli were longer than nonword stimuli. Stimuli also differed as a function of probability/density, $F(1, 60) = 10, p < .01$: Low-probability stimuli were longer than high-probability stimuli. There was no interaction between these two factors. The potential influence of differences in stimulus duration on children's performance is considered in the Results section.

Data Collection

Data collection took place in a quiet room at the child's day care center or in the first author's laboratory. Stimuli were blocked by lexicality. In addition, the nonwords were blocked by phonotactic probability, and the real words were blocked by neighborhood density. Experiment order was randomized across participants, and stimuli were randomized within blocks. Equal numbers of children participated in the eight experiment orders. For the real-word repetition experiment, participants were told that they would be hearing words they know played by the computer; for the nonword repetition experiment, they were told that they would be hearing "silly, made-up words" played by the computer. Participants were instructed to repeat the words and nonwords immediately, "just like the computer said it." For 2 s before the presentation of a stimulus, children were shown a cartoon picture of a police officer cupping his ear, to cue them to listen for the next word. After they repeated the word, participants were presented with a reinforcement picture of an unfamiliar cartoon animal. Each session began with two practice words in which the participant repeated the experimenter's live-voice productions and four digitized practice words that were presented from the computer. None of the practice items were included in the experiment.

During the last training phase and the entire experimental phase, stimuli were output from a Dell

Pentium III laptop computer through Audix powered speakers. The stimuli were played at a level of approximately 65 dB SPL, as calibrated before the experiment using the slow, dB-A scale of a portable sound-level meter located approximately 2 ft from the speakers (i.e., at the approximate location of the participant's head during the experiment). Children's speech was recorded directly on to the hard drive of a Dell Pentium III laptop, using a table-mounted microphone (Sony ECM 220t) placed approximately 15 cm from the participant's mouth. Speech was digitized at a sampling rate of 22.05 kHz with 16-bit quantization and low-pass filtered at 11.025 kHz to remove aliasing.

Analysis

Before completing acoustic analyses, items repeated incorrectly were removed from the analysis. The range of usable tokens for individual participants was 53 to the full set of 64 ($M = 62$, $SD = 3$, mode = 64). The eliminated tokens were distributed evenly between the two age groups. Moreover, the incorrectly repeated items did not differ as a function of lexicality or probability/density. These effects were confirmed by a three-factor mixed-model ANOVA. The dependent measure in this analysis was arcsine-transformed proportion of items correctly repeated. The within-subjects factors were lexicality and probability; the between-subjects factor was age. No effect was found of probability/density, $F(1, 29) < 1$, $p > .05$; lexicality, $F(1, 29) = 1.6$, $p > .05$; or age, $F(1, 29) < 1$, $p > .05$.

All of the temporal measures reported in this article were made using the Praat signal-processing software (Boersma & Weenink, 2002). A display containing a spectrogram and a waveform was generated. The first author marked the offset of the stimulus, the onset of the response, the offset of the response, and the onset and offset of the vowel within the response on that display. Durations were extracted from the file containing these labels automatically.

Reliability was gauged by having a second researcher (either the second or the third author) make the same measures independently for a large proportion of the data. Cases in which the differences exceeded 25 ms were measured a third time. Pearson product–moment correlations between measurements made by the first rater and those made by the second raters were .94 for response latency and .92 for response vowel duration, when pooled across the two participant groups and the four experimental conditions. When examined separately by group and condition, Pearson coefficients ranged from .89 (for young children's response latencies for low-probability nonwords) to .96 (for young children's vowel durations in high-probability nonwords). The average absolute difference, pooled across the two participant groups and four experimental conditions, was 8 ms for response latency (range = –25 to 10 ms) and 10 ms for vowel duration (range = –17 ms to 9 ms).

Response Latency

In a number of previous studies using this paradigm (i.e., Vitevitch & Luce, 1999), response latencies have been made from the onset of the stimulus to the onset of the response (*onset-to-onset* latencies). Thus, the duration of the different types of stimuli is a potential confounding factor. Munson (2001) and Munson and Solomon (2004) found that duration differs as a function of the phonotactic probability of nonwords and the neighborhood density of real words. The stimuli in this study showed this expected pattern. Indeed, we had anticipated this, as the stimuli in this article were also used in a parallel study examining children's ability to mimic stimulus duration in real-word and nonword repetition tasks (Munson, 2003). The design of that study required that the stimuli vary in duration. In the current study, we chose to measure the interval between the offset of the stimulus and the onset of the response (*offset-to-onset* latencies), so that the stimulus duration would not confound the repetition latency measures.

Before calculating mean offset-to-onset latencies, outlying data were removed. Responses that occurred greater than 2.5 *SD* above the mean for that participant were removed from the analysis. No responses occurred greater than 2.5 *SD* below the mean, and no responses began before stimulus offset. This was done to minimize the influence of poor attention on latency measures. Outliers occurred in less than 1% of the data and were distributed approximately evenly among the different stimulus types. In addition, latencies were not analyzed for items that were subsequently produced incorrectly or disfluently. For the purposes of this article, correct production was defined as any production in which the child did not delete a sound or make a manner- or place-of-articulation substitution. Some of the children produced age-appropriate /r/ distortions (i.e., errored productions of /r/ that were perceptually distant from /w/); these responses were included. For each participant, mean response latencies were calculated separately for high- and low-probability nonwords and for high- and low-density real words.

Response Duration

Before completing the regression analyses of whole-word duration and vowel duration, outlying data were removed, as were data from incorrect responses. There were fewer outlying data points for response durations than for response latencies. In general, outliers occurred when the child was not attending to the task or was affecting a highly stylized speaking mode. For each participant, mean vowel durations were calculated separately for high- and low-probability nonwords and for high- and low-density real words.

Results

A series of mixed-model ANOVAs was used to analyze the influence of lexicality, probability or neighborhood density, and age group, on response latency and response vowel duration. As indicated above, the stimuli did not vary in both phonotactic probability and neighborhood density: The low-density real words were not lower in phonotactic probability than the high-density real words. Therefore, we could not analyze the data with a series of three-factor ANOVAs examining probability/density as a single factor, as had been done in research in which probability and density varied together (e.g., Vitevitch & Luce, 1999). For each dependent measure, three separate ANOVAs were conducted. The first was a two-factor mixed-model ANOVA examining the influence of age group (the between-subjects factor) and lexicality (the within-subjects factor) on the dependent measure. In this ANOVA, measures for high- and low-probability nonwords and high- and low-density real words were averaged together. The other two ANOVAs were two-factor mixed-model ANOVAs examining real-word repetition and nonword repetition performance separately. In these analyses, the between-subjects factor was age group, and the within-subjects factor was either phonotactic probability (for the nonwords) or neighborhood density (for the real words).

Response Latency

Offset-to-onset latencies. The ANOVA examining the influence of lexicality on response latencies revealed a significant main effect of lexicality, $F(1, 29) = 4.3$, $p < .05$, partial $\eta^2 = .13$. Real words were repeated with shorter latencies (M = 442 ms, SD = 123 ms) than nonwords (M = 481 ms, SD = 141 ms). No main effect of age group was found, $F(1, 29) < 1$, $p > .05$. The older children repeated items 10 ms faster than younger children, but this difference was not statistically significant (M = 460 ms, SD = 147 ms, for older children; M = 470 ms, SD = 107, for younger children). There was a significant interaction between lexicality and age group, $F(1, 29) = 4.5$, $p < .05$, partial $\eta^2 = .14$. Real words and nonwords were produced with nearly identical latencies by the younger children (M = 469 ms, SD = 93 ms, for nonwords; M = 470 ms, SD = 111 ms, for real words). This difference did not achieve significance in a post hoc test of significant main effects, F(1, 15) < 1, $p > .05$. In contrast, there was a large difference in repetition latencies between nonwords (M = 508 ms, SD = 144 ms) and real words (M = 416 ms, SD = 119 ms) in older children. This difference did achieve significance in a post hoc test of significant main effects, $F(1, 14) = 5.4$, $p < .05$.

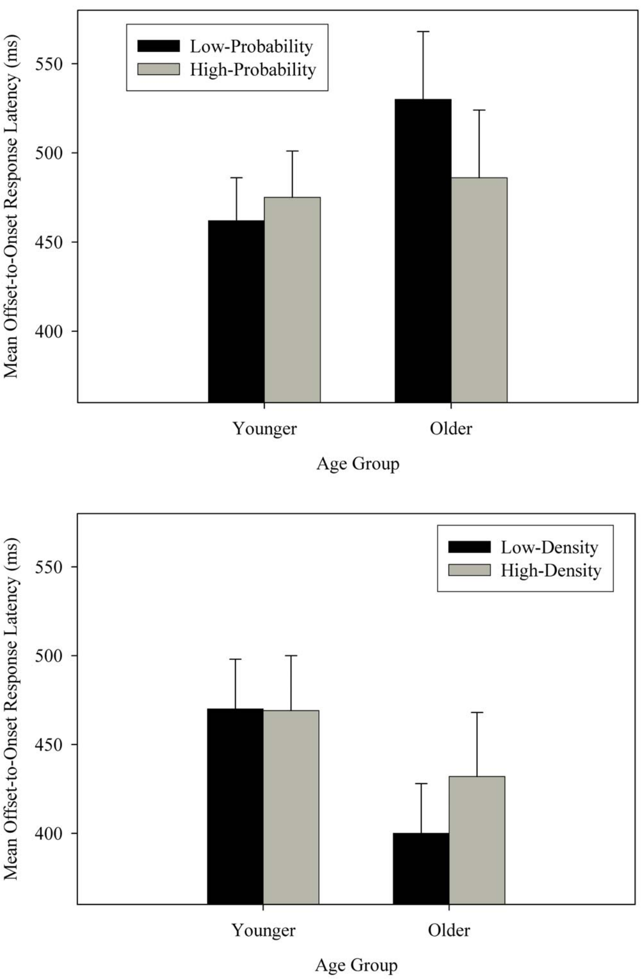
The next ANOVA examined the influence of age group and phonotactic probability on nonword repetition latencies. Again, the ANOVA revealed no significant effect of age group, $F(1, 29) < 1$, $p > .05$. In addition, there was no significant main effect of phonotactic probability, F(1, 29) = 1.8, $p > .05$. However, there was a significant interaction between age group and phonotactic probability, $F(1, 29) = 6.2$, $p < .05$, partial $\eta^2 = .18$. In the older children, high-probability nonwords were repeated with shorter latencies (M = 486 ms, SD = 146 ms) than low-probability nonwords (M = 530, SD = 146 ms). This achieved significance in a post hoc test of significant main effects, $F(1, 14) = 10.4$, $p < .01$. This pattern was also true for the younger children (M = 462 ms, SD = 97 ms, for low-probability nonwords; M = 475 ms, SD = 102 ms, for high-probability nonwords). However, a post hoc test of simple main effects showed that this difference did not achieve statistical significance, $F(1, 15) < 1$, $p > .05$.

The third ANOVA examined the influence of age group and neighborhood density on real-word repetition latencies. Once again, no significant main effect of group was found, F(1, 29) = 1.7, $p > .05$. There was no significant main effect of neighborhood density, $F(1, 29) = 1.2$, $p < .05$. However, there was a significant interaction between age group and neighborhood density, $F(1, 29) = 4.3$, $p < .05$, partial $\eta^2 = .12$. Post hoc tests of significant main effects showed no effect of neighborhood density on younger children's repetition latencies, $F(1, 15) < 1$, $p > .05$. However, a significant effect was found for older children, $F(1, 14) = 5.2$, $p < .05$, who repeated high-density real words with longer latencies (M = 431 ms) than low-density real words (M = 400 ms).

Response latencies are illustrated in Figure 1. As this figure shows, the older children performed similarly to adults in previous research. Nonwords were repeated with longer latencies than real words. High-density real words were repeated with longer latencies than low-density real words. Low-probability nonwords were repeated with longer latencies than high-probability nonwords. In contrast, there was no systematic effect of lexicality, probability, or neighborhood density in the younger children.

Onset-to-onset latencies. A surprising finding of the analysis of response latency was the lack of an effect of phonotactic probability on younger children's response latencies. Research had shown an effect of phonotactic probability on nonword repetition accuracy and duration

Figure 1. Mean offset-to-onset response latency (+ 1 *SEM*) for nonword (top) and real-word (bottom) repetitions.



in children (e.g., Munson, 2001), as well as effects on processing times in adults (e.g., Vitevitch & Luce, 1998, 1999). Studies on adults' processing times had used onset-to-onset response latencies. To examine whether the differences between our finding and that of earlier studies was due to the use of offset-to-onset measures, we completed a parallel set of analyses examining the onset-to-onset latencies. The duration of our stimuli differed as a function of lexicality and probability. Therefore, onset-to-onset latencies could not be measured for the entire set of 64 stimuli. Instead, 8 stimuli were chosen from each condition. These 8 stimuli did not differ significantly in duration as a function of either lexicality or density, nor did these factors interact, $F(1, 30) < 1$, $p > .05$, for all three tests. The stimuli used in this analysis are underlined in Table 2.[1]

As in the analysis of offset-to-onset latencies, three separate ANOVAs were used to examine these data. The first analysis examined the influence of age group and lexicality. A significant main effect of lexicality was found, $F(1, 29) = 5.2$, $p < .05$, partial $\eta^2 = .15$. Nonwords were repeated with longer response latencies ($M = 1{,}005$ ms, $SD = 114$ ms) than real words ($M = 960$ ms, $SD = 113$ ms). No significant effect of age was found, $F(1, 29) < 1$, $p > .05$. Lexicality also interacted with age group, $F(1, 29) = 6.6$, $p < .05$, partial $\eta^2 = .19$. Older children repeated nonwords with longer latencies than real words ($M = 1{,}033$ ms, $SD = 134$ ms, for nonwords; $M = 941$ ms, $SD = 106$ ms, for real words). Younger children produced very similar latencies for both types of stimuli ($M = 979$ ms, $SD = 88$ ms, for nonwords; $M = 985$ ms, $SD = 117$ ms, for real words).

The next ANOVA examined the influence of phonotactic probability and age group on nonword repetition latencies. A significant main effect of phonotactic probability was found, $F(1, 29) = 19.4$, $p < .01$, partial $\eta^2 = .40$. High-probability nonwords were repeated with shorter latencies ($M = 968$ ms, $SD = 124$ ms) than low-probability nonwords ($M = 1{,}042$ ms, $SD = 125$ ms). No significant main effect of age group was found, $F(1, 29) = 1.7$, $p > .05$. Age group and phonotactic probability interacted, $F(1, 29) = 4.4$, $p < .05$, partial $\eta^2 = .13$. Both groups of children repeated high-probability nonwords with shorter response latencies than low-probability nonwords (for older children, $M = 977$ ms, $SD = 139$ ms, for high-probability nonwords; $M = 1{,}088$ ms, $SD = 147$ ms, for low-probability nonwords; for younger children, $M = 959$ ms, $SD = 111$ ms, for high-probability nonwords; $M = 999$ ms, $SD = 85$ ms, for low-probability nonwords). This result stands in contrast to the results for the offset-to-onset latencies, in which a significant influence of phonotactic probability was found for older children only. The effect of phonotactic probability on nonword repetition latencies achieved statistical significance in post hoc tests for both groups, $t(15) = –2.2$, $p < .05$, for younger children; $t(14) = –4.3$, $p < .01$, for older children). Note that the raw difference was larger for older children (111 ms) than for younger children (40 ms). That is, this analysis had in common with the earlier analysis that it found an increase in phonotactic probability effects from younger to older children.

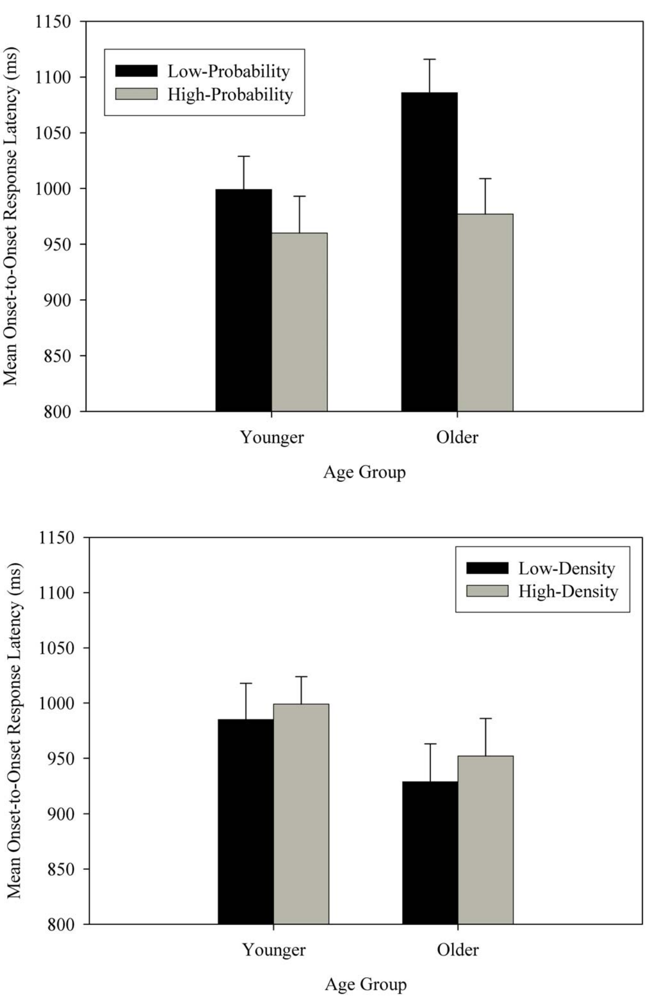
A two-factor ANOVA examined the influence of neighborhood density and age group on onset-to-onset response latencies in real-word repetition. Again, no effect of age group was found, $F(1, 29) = 1.6$, $p < .05$. No significant main effect of neighborhood density was

[1]When onset-to-onset latencies were used for all 64 stimuli, the only significant main effects were for phonotactic probability and neighborhood density. However, the effect of neighborhood density was in the opposite-than-predicted direction: High-density real words were repeated with shorter onset-to-onset latencies than low-density real words. In addition, there was a significant interaction between lexicality and age, $F(1, 29) = 5.6$, $p < .05$, which arose because there was a larger effect of lexicality for the older children than for the younger. However, these results likely reflect the confounding influence of stimulus duration on response latency.

found, $F(1, 29) < 1$, $p > .05$. While there were small differences in the raw response latencies for the two word types (M = 977 ms, SD = 134 ms, for high-density real words; M = 958 ms, SD = 106 ms, for low-density real words), this difference did not achieve statistical significance. For both groups, high-density real words were repeated with longer response latencies than low-density real words (for older children, M = 952 ms, SD = 112 ms, for high-density real words; M = 929 ms, SD = 112 ms, for low-density real words; for younger children, M = 999 ms, SD = 151 ms, for high-density real words; M = 985 ms, SD = 100 ms, for low-density real words). However, in post hoc tests, this difference achieved statistical significance for the older group of children only, $t(14) = –2.1$, $p < .05$.

The onset-to-onset response latencies are shown in Figure 2. As this figure shows, both groups of children showed patterns of response latencies that were similar to those demonstrated by adults in previous research.

Figure 2. Mean onset-to-onset response latency (+ 1 *SEM*) for nonword (top) and real-word (bottom) repetitions.



However, the effect of neighborhood density on real-word repetition latencies was significant for the older group of children only. Moreover, larger differences in raw latencies across conditions were found for both stimulus types for the older group of children.

Vowel Duration

Finally, three ANOVAs examined the influence of lexicality, phonotactic probability, and neighborhood density on vowel duration. The first was a two-factor mixed-model ANOVA examining the influence of age group and lexicality on duration. A significant main effect of lexicality was found, $F(1, 29) = 58.1$, $p < .001$, partial $\eta^2 = .67$. Vowels in nonwords were significantly shorter than vowels in real words (M = 206 ms, SD = 34 ms, for nonwords; M = 244 ms, SD = 44 ms, for vowels in real words). However, no significant effect of age group was found, $F(1, 29) < 1$, $p > .05$. Moreover, these factors did not interact. The lack of an effect of age was inconsistent with some previous research on children's speech development but consistent with the performance of this cohort of children on two other real-word/nonword repetition tasks (Munson, 2004; Munson & Babel, in press).

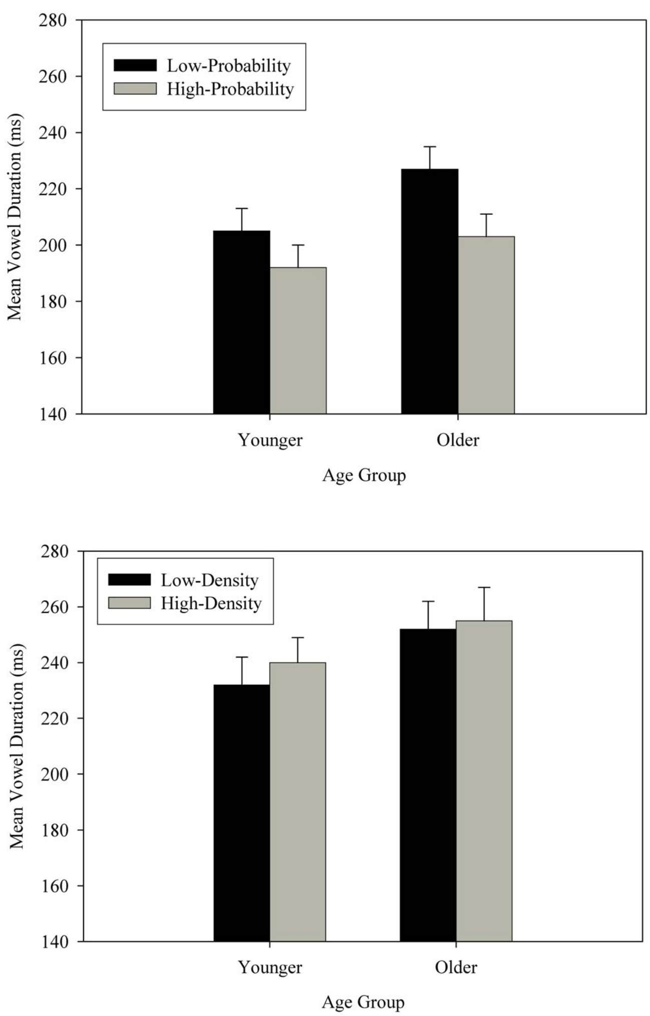
The next ANOVA examined the influence of age-group and phonotactic probability on the duration of vowels embedded in nonwords. A significant main effect of phonotactic probability was found, $F(1, 29) = 17.6$, $p < .01$, partial $\eta^2 = .38$. There was no significant effect of age, $F(1, 29) < 1$, $p > .05$. Moreover, the two factors did not interact. In both groups of children, vowels in high-probability nonwords were repeated with shorter durations than vowels in low-probability nonwords (M = 198 ms, SD = 32 ms, for vowels in high-probability nonwords; M = 216 ms, SD = 34 ms, for vowels in low-probability nonwords, pooled across groups). A post hoc test of significant main effects found this difference to be statistically significant in both groups of children. The finding regarding nonwords supports previous investigations (Edwards et al., 2004; Munson, 2001) that found that children produce longer speech-sound durations when sounds are embedded in low-probability sequences. This reflects a difficulty in generalizing fluent production of vowels to sequences that are unattested or infrequently attested in the lexicon.

Finally, a two-factor ANOVA examined the influence of neighborhood density on vowel duration. In this ANOVA, neither of the main effects was significant, $F(1, 29) < 1$, $p > .05$, for neighborhood density; $F(1, 29) = 1.7$, $p < .05$, for age group), nor did they interact significantly. Vowels in high-density real words were repeated with longer durations than vowels in low-density real words (M = 248 ms, SD = 41 ms, for high-density real words, M = 241 ms, SD = 41 ms, for low-density real words, pooled across groups); however, this difference did not achieve significance in post hoc testing, either for the group as a whole or for either group when examined separately. Vowel duration data are shown in Figure 3, which plots data separately for nonwords (top) and real words (bottom).

Relations Among Measures

The final analysis examined relations among the experimental measures of lexical competition and phonological facilitation and standard measures of the participants' phonological and lexical development. In this section, we present two analyses. First, we examined correlations between measures of lexical competition and phonological facilitation to determine whether these two processes were independent or related. Second, we used hierarchical multiple regression analysis to examine relationships between experimental measures and the two clinical measures: EVT raw scores and GFTA-2 raw scores. By examining relations between the experimental measures and the clinical measures of vocabulary size and phonological accuracy, we hoped to infer the source of developmental changes in phonological facilitation and lexical competition. For example, previous research (Edwards et al., 2004; Munson et al., 2005) found that phonotactic probability effects are related to vocabulary size: Children with larger vocabularies show smaller effects of phonotactic probability on nonword repetitions, even when the effects of age, phonological accuracy, and speech perception are statistically controlled. This result suggests that developmental changes in phonotactic probability are related to increases in vocabulary size.

Figure 3. Mean duration of vowels (+ 1 *SEM*) in nonwords (top) and real words (bottom).



For these analyses, six summary measures were created from the reaction time and vowel duration measures. The goal was to create measures that would reflect the degree to which high-probability nonwords showed more facilitation than low-probability nonwords and the degree to which high-density real words showed more inhibition relative to low-density real words. For each measure (offset-to-onset reaction time, onset-to-onset reaction time, and vowel duration), a measure of the degree of lexical competition was created by dividing each participant's average performance on the high-density real words by their performance on the low-density real words. Higher values of this variable indicated greater lexical competition. Three measures of phonological facilitation were also calculated by dividing average performance on the high-probability nonwords by their average performance on the low-probability nonwords. Higher values on this measure indicated greater phonological facilitation. Simple correlations (Pearson's *r*) were calculated between these variables, the EVT standard score, and the GFTA-2 percentile rankings. An a level of .01 was used to evaluate significance.

When the entire group of participants was examined together, no significant correlations were found, either among the experimental measures or between the experimental measures and the EVT/GFTA-2. When the groups were examined individually, one significant correlation was found between two experimental measures for the younger group of children. The lexical competition measure based on the onset-to-onset response latency was significantly correlated with the phonological facilitation measures based on the same measure. Children who evidenced more lexical competition (i.e., a larger difference in response latency between high- and low-density real words) also evidenced more phonological facilitation (i.e., a larger difference in response latency between high- and low-probability nonwords). This same relationship held true for the measure of vowel duration and the measure of onset-to-onset latency, although these were only significant at the .05 level. No other correlations were significant for this group, and none were significant for the older children. The correlation coefficients are presented in Tables 3, 4, and 5.

With a series of six hierarchical multiple regression analyses, we examined predictors for the six derived measures of phonological facilitation and lexical competition. In each of these regressions, age was forced as the first variable. Raw score on the GFTA-2 and the EVT were entered in the second step if they accounted for a significant proportion of variance ($\alpha < .05$). None of the independent measures predicted a significant proportion of variance in any of the six dependent measures. This result stands in contrast to the results of Edwards et al. (2004) and Munson et al. (2005), who found that measures of vocabulary size predicted a significant proportion of accuracy in the difference in repetition accuracy between high- and low-probability nonwords. That measure was roughly analogous to the phonological facilitation measures presented in this article, in that it was a measure of the extent to which phonotactic probability facilitated nonword repetition.

Discussion

Summary

This article examined two measures taken from preschool and school-age children's real-word and nonword repetitions. This study examined correct repetitions only. One unexpected observation that we made of these data was that children's real-word and nonword repetitions were highly accurate: Many participants performed perfectly on both tasks. Consequently, there were no significant effects of lexicality, probability/density, or age on repetition accuracy. The stimuli for this study were chosen because they were highly intelligible to normal adult listeners when presented at a level 5 dB SPL below the level used for the experiment. This finding provides indirect evidence that accuracy on repetition tasks in which phonotactic probability and neighborhood density are manipulated may be related to the audibility of the stimuli in the different categories, as has been proposed by some researchers (e.g., Dirks et al., 2001). Moreover, the high rate of accurate repetitions minimized the number of tokens that needed to be eliminated from the latency and duration analyses.

The first measure taken from children's correct responses was offset-to-onset response latency. Here, it was found that younger children showed no difference in response latencies as a function of lexicality, phonotactic probability, or neighborhood density. In contrast, the older group of children demonstrated response latencies similar to those of adults in previous research. Real words were processed more quickly than nonwords. High-probability nonwords were processed more quickly than low-probability ones, and high-density real words were processed more slowly than low-density ones. In a follow-up to this finding, onset-to-onset latencies were examined for a subset of the stimuli matched in stimulus duration. Here, it was also found that only the older group of children showed an effect of phonological neighborhood density on real-word repetition latencies. In this analysis, however, both groups of children showed an

Table 3. Correlations among measures for entire group of participants.

	1	2	3	4	5	6	7	8	9	10	11
1. Age	—										
EVT											
2. Standard score	−.12	—									
3. Raw score	.82**	.30	—								
GFTA-2											
4. Percentile rank	−.33	.13	−.36*	—							
5. Raw score	−.47**	−.20	−.40*	−.56**	—						
Offset-to-onset latencies											
6. Lexical competition	.14	−.26	.04	−.35	.16	—					
7. Phonological facilitation	−.20	.30	−.15	.27	−.05	.16	—				
Onset-to-onset latencies											
8. Lexical competition	.07	.10	.00	−.08	.01	.64**	.38	—			
9. Phonological facilitation	−.20	.24	−.25	.22	−.02	.18	.69*	.27	—		
Vowel duration											
10. Lexical competition	−.19	.21	−.12	−.07	.20	.22	.26	.36*	.10	—	
11. Phonological facilitation	−.21	−.08	−.04	−.05	.12	.18	.08	.02	−.16	.27	—

Note. EVT = Expressive Vocabulary Test; GFTA-2 = Goldman–Fristoe Test of Articulation–2; GFTA raw score = number of errors.
*$p < .05$. **$p < .01$.

Table 4. Correlations among measures for the younger group.

	1	2	3	4	5	6	7	8	9	10	11
1. Age	—										
EVT											
2. Standard score	.04	—									
3. Raw score	.69**	.31	—								
GFTA-2											
4. Percentile rank	−.47	.45	−.12	—							
5. Raw score	−.05	−.53*	−.08	−.88**	—						
Offset-to-onset latency											
6. Lexical competition	.15	−.19	.02	−.46	.56*	—					
7. Phonological facilitation	.33	.32	.17	.17	−.29	.70**	—				
Onset-to-onset latencies											
8. Lexical competition	.03	.29	.02	.08	.07	.70**	.71**	—			
9. Phonological facilitation	−.08	.41	−.27	.11	−.15	.23	.71**	.50*	—		
Vowel duration											
10. Lexical competition	−.19	.21	−.18	−.04	.17	.39	.28	.58*	.18	—	
11. Phonological facilitation	−.09	−.35	.00	.06	.08	.27	−.03	.13	−.52*	.47*	—

Note. EVT = Expressive Vocabulary Test; GFTA-2 = Goldman–Fristoe Test of Articulation–2; GFTA raw score = number of errors.
*$p < .05$. **$p < .01$.

effect of phonotactic probability on nonword repetition latency. The size of the effect was slightly larger in older children. The pattern of responses shown by the older children is the same as the pattern that has been demonstrated by adults in previous research (e.g., Vitevitch & Luce, 1998, 1999). The longer response times associated with high-density words have been attributed to lexical competition. When listeners hear words that are phonetically similar to other real words in the lexicon, those other words compete as potential responses, and this competition slows processing. In contrast, the shorter response times associated with high-probability nonwords have been attributed to phonological facilitation. Nonwords that contain sequences of phonemes occurring in many other real words are processed more rapidly than ones containing infrequent sequences of phonemes. The results of the latency analysis suggest that the influence of lexical competition and phonological facilitation on processing time increases during development.

Table 5. Correlations among measures for the older group.

	1	2	3	4	5	6	7	8	9	10	11
1. Age	—										
EVT											
2. Standard score	.05	—									
3. Raw score	.47	.86	—								
GFTA-2											
4. Percentile rank	.17	−.52	−.46*	—							
5. Raw score	−.38	.13	−.08	−.74*	—						
Offset-to-onset latencies											
6. Lexical competition	−.48*	−.27	−.35	−.10	.17	—					
7. Phonological facilitation	.54*	.13	.39	.21	−.42	−.01	—				
Onset-to-onset latencies											
8. Lexical competition	−.28	−.21	−.32	−.22	.47*	.56*	−.24	—			
9. Phonological facilitation	.39	−.04	.17	.24	−.40	.32	.59*	.05	—		
Vowel duration											
10. Lexical competition	−.15	.19	.17	−.29	.07	.04	.06	−.22	−.19	—	
11. Vowel duration	−.22	.10	.17	−.27	.06	.18	.09	−.08	.03	.01	—

Note. EVT = Expressive Vocabulary Test; GFTA-2 = Goldman–Fristoe Test of Articulation–2; GFTA raw score = number of errors.
*$p < .05$.

The two reaction time analyses have in common that they both found an effect of phonological neighborhood density on real-word repetition latencies for the older children only. However, significant effects of phonotactic probability on the younger children's nonword repetition latency were only found when an onset-to-onset latency measure was used. This difference highlights the methodological importance of the choice of onset-to-onset versus onset-to-offset latencies. Previous investigations of real-word and nonword repetition (e.g., Vitevitch & Luce, 1998, 1999) have used onset-to-onset response latencies. One constraint associated with this measure is that stimuli in the different conditions (real words vs. nonwords, high-probability/density vs. low-probability/density) must be matched for duration, or the stimulus duration will confound the response latency measure. However, research has shown that phonological neighborhood density and phonotactic probability influence real-word and nonword duration (e.g., Munson, 2001; Munson & Solomon, 2004): High-probability phoneme sequences and high-density words are produced with shorter acoustic durations than low-probability/low-density ones. The stimuli in this study showed this pattern. Indeed, this variation was part of the design of a parallel study examining the extent to which children are able to mimic the durations of real-word and nonword stimuli (Munson, 2003). Because the stimulus durations were not equivalent across different stimulus types, neighborhood densities, and phonotactic probabilities, offset-to-onset latencies were used instead of onset-to-onset latencies. However, the results from the analysis of offset-to-onset latencies were somewhat different from an analysis of onset-to-onset latencies for a subset of stimuli matched in duration. Specifically, measurement sensitivity seemed better for the onset-to-onset analysis, in that it showed phonological facilitation in even the youngest group, as might be predicted based on previous studies of children's perceptual development. Taken together, these findings highlight the importance of using onset-to-onset measures in stimuli that are matched for duration, even though such stimuli are not representative of the high- and low-density stimuli that listeners encounter during naturalistic language processing.

One surprising aspect of the analyses of response latencies was the lack of a significant age effect. Research (e.g., Kail, 1991) had found developmental increases in speed of processing across different cognitive, linguistic, and motoric tasks. While the older group of children did repeat words and nonwords an average of 10 ms faster than children in the younger group, this did not achieve statistical significance. When examining individual conditions independently, none of the individual conditions showed a significant age-related difference in response latency, although one age-related change in repetition latency did approach significance: Older children's repetitions of low-density real words were 70 ms faster than younger children in the offset-to-onset latency analysis, $t(29) = 1.8$, $p = .08$. That is, in the one condition in which age had a marginally significant effect on response times, that difference was in the expected direction. One potential explanation for this null result is that limitations in statistical power may have resulted in the nonsignificant effect of age. The response times in both groups of participants were highly variable, and a larger group of participants may have been needed to observe a significant effect of age on performance.

When examining repetition duration, both groups of children were found to produce vowels in low-probability nonwords with longer durations than vowels in high-probability nonwords. The nonwords were designed so that each of the two diphone sequences constituting the nonword were approximately equal in probability; thus, the vowels were members of either two low-probability diphone sequences or two high-probability diphone sequences. In keeping with Munson (2001) and Edwards et al. (2004), we can interpret this finding as evidence that children experienced difficulty generalizing fluent, rapid vowel production to sequences of phonemes that occurred in few known words. This effect was similar in size for both groups of participants, in contrast to previous studies, which had found developmental decreases in phonotactic probability effects on production. This finding supports previous claims (Edwards et al., 2004; Munson, 2001; Munson et al., 2005) that children's productive control over phonemes independent from the words in which they occur increases in development.

Finally, this study did not find a statistically significant relationship between vocabulary size measures and measures of lexical competition or phonological facilitation. At least two other studies (Edwards et al., 2004; Munson et al., 2005) had found a relationship between a measure of phonological facilitation and measures of vocabulary size. However, the measure of phonological facilitation in both of these studies was a measure of repetition accuracy rather than measures of response duration or latency, as were used in the current article. The vocabulary measures used as predictors in this study and in previous research are relatively static estimates of the sizes of children's vocabularies. It may be that a predictive relationship would have been found in this study if our measure of lexical knowledge had been a more dynamic measure, such as a measure of processing speed during a confrontation naming task, rather than a static estimate of vocabulary size. That is, the static measure of vocabulary size may not have the measurement sensitivity needed to detect the relationship between vocabulary growth and developmental changes in lexical competition or phonological facilitation. Indeed, the results of one recent investigation (Kurtz, Munson,

& Windsor, 2004) suggest that static measures of vocabulary size might not have the measurement sensitivity needed to predict the magnitude of phonological facilitation effects across different tasks and different age ranges. Kurtz et al. examined predictors of a measure of phonological facilitation (the difference in repetition accuracy between high- and low-probability nonwords) in typically developing children and children with language impairment age 5–13 years. In that study, static measures of vocabulary size predicted the magnitude of phonological facilitation effects. However, a dynamic measure of linguistic knowledge—performance on a test of morphology, semantic knowledge, and syntactic knowledge—predicted a far greater proportion of variance in the same measure. Kurtz et al.'s result suggests that dynamic measures of linguistic knowledge might have greater sensitivity than static measures of vocabulary size to predict developmental changes in phonological facilitation.

General Discussion

Overall, there were two major findings in this study. The first was that the effect of phonological neighborhood density on real-word repetition times increases with age. In both the offset-to-onset and onset-to-onset analyses, this effect was present for the older group of children only. One possible interpretation of this effect can be found in research on the development of lexical neighborhoods in children (e.g., Charles-Luce & Luce, 1990, 1995). Young children's lexicons are smaller than those of older children and are not likely to contain high-density neighborhoods. For these children, lexical processing is not subject to competition. As children learn more lexical items, their lexicons are increasingly likely to contain a cohort of phonetically similar words constituting a high-density neighborhood. The words residing in these high-density neighborhoods would be subject to competition effects. This finding fits well with a growing body of literature showing effects of lexical growth and lexical neighborhood structure on children's linguistic processing. For example, both Garlock et al. (2001) and Storkel (2002) showed an effect of phonological neighborhood density on phonological processing. In both studies, children appeared to have more detailed phonological representations of words in dense phonological neighborhoods than in sparse neighborhoods.

The second principal finding in this study was that phonological facilitation in nonword repetition reaction times increases with development. Previous research on nonword repetition in children (Edwards et al., 2004; Munson, 2001; Munson et al., 2005) found that even very young children show evidence of phonological facilitation in production: Children in these studies repeated high-probability sequences of phonemes more accurately and with shorter durations than low-probability sequences. Indeed, this effect was replicated in the analysis of vowel duration in the current study. Given that phonological facilitation effects can be found in early production, we might have expected them to be present in processing and to be indicative of a more general phonological facilitation effect pervading both perception and production. However, these previous studies have interpreted these developmental decreases in phonotactic-probability effects as indicative of the development of representations of phonemes as separate from the word shapes in which they occur. Perhaps phonological facilitation in nonword processing, which we observed to increase during development, is related to children having developed robustly abstracted phonological representations. That is, phonotactic probability can only affect processing times after children have begun to develop robustly abstracted representations for phonemes. The phonotactic probability effects in production, however, may reflect children's ability to use familiar articulatory patterns in producing novel phoneme sequences and novel words. A related finding was that the interaction between lexicality and processing times increased with age. In younger children, repetition latencies for real words and nonwords were similar. In older children, as in adults (e.g., Vitevitch & Luce, 1998, 1999), repetition latencies for words were shorter than those for nonwords. This developmental change may be related to the differences in rate of word learning in the two groups of children. Preschool children are highly engaged in the process of word learning. Indeed, children are typically able to form associations between a novel phonological form and a referent even with only minimal exposure (e.g., Carey, 1978). Older children continue to learn words, but their word learning is more likely than younger children's to involve making new morphologically complex derivations from known forms (e.g., Anglin, 1993). The lack of an asymmetry between real words and nonwords in young children may reflect the fact that they are actively learning words; hence, they are more accustomed to hearing and processing novel forms. Older children's word learning is less likely to involve associations between novel words and referents; therefore, they process novel words less rapidly than known words.

Future research in this area should explore the predictors of developmental changes in phonological facilitation and lexical competition in production and processing, to better understand the relationship between lexical and phonological development. In particular, future research should examine a larger cohort of children in the same age range, to determine whether lexical competition and phonological facilitation develop in tandem or independently. This study found some evidence that the two develop in tandem: Children in the younger group who showed evidence of greater phonological facilitation also showed great lexical competition. A finding that these develop in tandem in a larger cohort of children would suggest that they both reflect the effects of lexical growth. Specifically, this would suggest that lexical growth leads to children developing cohorts of phonetically similar words that compete with each other during processing and that these neighborhoods are represented by phonological units that facilitate the processing of nonwords. Future research should also examine relations between measures of phonological facilitation and a variety of measures of lexical knowledge and lexical processing, to examine whether these measures predict developmental changes in phonological facilitation and lexical competition.

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