Effects of Neighborhood Density and Noise on Children's Word Learning

By

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Abstract

Studies show that words are organized with similarity neighborhoods based on similar sound structure. Some words have many similar sounding words, while others have few. The number of neighbors a word has is called neighborhood density, which is known to influence word learning. Specifically, words with few neighbors are learned more accurately early in training perhaps because these words play a role in triggering the learning of a novel word. In contrast, words with many neighbors are learned more accurately later in training and post training perhaps because these words play a role in the construction of a new lexical representation in long-term memory and in the connection of the newly constructed lexical representation with existing representations (Storkel, Armbrüster, & Hogan, 2006; Storkel, Bontempor, Aschenbrenner, Maekawa, & Lee, 2013; Storkel & Lee, 2011). However, these findings were obtained in a quiet listening condition, providing little information about the effect of the environment where word learning typically takes place.

The goal of this study was to examine whether noise alters the effect of neighborhood density on word learning. Seventy-seven typically developing 4- and 5-year-old preschool children were randomly assigned to one of three listening conditions: 0dB, +6dB, and +15dB signal-to-noise ratio (SNR). Sixteen consonant-vowel-consonant nonword-novel object referent pairs were embedded in two stories for training; neighborhood density for the nonwords varied from low to high. Nonword stimuli and audio narrative scripts for stories were digitally mixed with broadband white noise at 0dB, +6dB, and +15dB SNR. Learning was measured using a picture naming task and a referent identification task. Six cycles of story training-measures of learning were completed with two no training points each after the third and sixth measures of learning.

Logistic multi-level modeling (MLM) revealed different patterns of word learning depending on the tasks. Only in the naming task, a significant effect of noise and an interaction between noise and neighborhood density were found at +6dB SNR compared to 0dB SNR. Specifically, results showed that (1) word learning was better at 6dB SNR than 0dB SNR; (2) no significant effect of density was found and this non-significance persisted over time. However, the high density advantage started to emerge at +6dB SNR and +15dB SNR; and (3) the difference between +6dB SNR and 0dB SNR was greater as density increased. In addition, in both naming and referent identification tasks, word learning increased over time with significant forgetting of words in the naming task and a trend of memory consolidation in the referent identification when no training was occurred.

These results provide the evidence that word learning declines as listening environment worsen. The results indicate that noise hinders children's ability to use lexical representations, which adversely influences the whole process of word learning (i.e., triggering, configuration, and engagement). The results also imply that high density words are more sensitive to listening condition than low density words. In addition, the naming task that requires more detailed lexical representation is more sensitive to noise than the referent identification task.

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Introduction

Children learn words in the context of other words they know. Known words have a lexical representation and a semantic representation in long-term memory. These representations may influence children’s word learning. Specifically, the existing representations may help children form rudimentary representations of a novel word even after only a brief exposure to the word. As exposures to the target words accumulate, children can refine these rudimentary representations. Thus, the existing representations help children to learn novel words, and, in turn, word learning can help the existing representations to be more fully-developed. Although children must learn both lexical and semantic representations, this study will focus primarily on lexical representations.

Lexical Representations in Long-Term Memory

Lexical representations of words in long-term memory are organized into similarity neighborhoods based on phonological similarity (Luce & Pisoni, 1998). The number of neighbors of a word is called neighborhood density. Neighborhood density has typically been operationally defined as all the words that differ by only one phoneme including a phoneme substitution, addition, or deletion (Charles-Luce & Luce, 1990; Goldinger, Luce, & Pisoni, 1989; Luce & Pisoni, 1998). Words with many neighbors are said to be located in dense neighborhoods while words with few neighbors are said to be located in sparse neighborhoods. For example, /bæt/ (“bat”) has many neighbors such as /kæt, bæk, fæt, hæt, mæt, næt, pæt, ræt, sæt, ðæt, bet, bit, bɪt, baɪt, bot, baut, but, bɔt, bʌt, æt, bræt, bæd, bæʒ, bæm, bædʒ, bæs, bæθ, bætəl/ while /wɔtʃ/ (“watch”) has few neighbors such as /wɪtʃ, wɔk, wɔl, wɔʃ/. Many studies have demonstrated that neighborhood density influences word learning.

When a novel word is encountered, three processes of word learning are thought to be involved: triggering, configuration, and engagement (Storkel & Adlof, 2009; Storkel, Armbrüster, & Hogan, 2006; Storkel, Bontempor, Aschenbrenner, Maekawa, & Lee, 2013; Storkel & Lee, 2011). In terms of triggering, a novel word must be recognized as new so that learning can be initiated. The input activates representations of known words in long-term memory. However, if the input is a novel word, the input will not have an exact match with an existing lexical representation in long-term memory. This lack of a match between the input and the child's representations in long-term memory is thought to trigger learning processes (Storkel & Adlof, 2009; Storkel et al., 2013; Storkel & Lee, 2011). If a novel word has few phonologically similar neighbors, the mismatch will be greater than when a novel word has many phonologically similar neighbors. Thus, novel words in sparse neighborhoods facilitate initiation of word learning (Storkel & Adlof, 2009; Storkel et al., 2013; Storkel & Lee, 2011).

In terms of configuration, once word learning is triggered, a new lexical representation for the novel word will be created in long-term memory and working memory will be involved in this process. Specifically, a novel phonological form of the novel word will be held in working memory for a short period of time while a new lexical representation for the novel word is created in long-term memory. A novel word from a dense neighborhood will facilitate the involvement of working memory in configuration of a new lexical representation by activating other words from its dense neighborhood in long-term memory and getting a return activation from its neighbors. As a result, its phonological form will be held in working memory more accurately and longer than that of words from sparse neighborhoods. Initially, configuration of the newly created lexical representation may be imperfect after only a brief exposure to the word, resulting in creation of a rudimentary representation (Gershkoff-Stowe, 2002; McGregor, Sheng,

& Ball, 2007; Metsala & Walley, 1998). However, with additional exposures to the word, the lexical representation is updated, resulting in construction of more refined and robust lexical representation in long-term memory (Storkel & Adlof, 2009; Storkel et al., 2006, 2013; Storkel & Lee, 2011).

In terms of engagement, once a new lexical representation is created, it needs to be integrated with existing representations. That is, the new lexical representation in long-term memory must form connections with existing lexical representations. This period of engagement appears to occur separately from the period of configuration. In other words, configuration occurs when one is exposed to a novel word while engagement occurs after exposure to the novel word, potentially off-line during sleep. This makes the period of engagement more extended (Gaskell & Dumay, 2003; Leach & Samuel, 2007). New representations that form connections with many existing representations (i.e., dense neighborhoods) may develop stronger representations than new representations that form connections with fewer existing representations (i.e., sparse neighborhoods) (Storkel et al., 2006, 2013; Storkel & Hoover, 2010a; Storkel & Lee, 2011).

The Effect of Noise on the Neighborhood Density Effect in Word Learning

Past studies of neighborhood density have examined word learning in a quiet environment. However, children are surrounded by noise. In particular, classrooms where children spend many hours and develop their vocabulary have been known to be noisier than they should be (Crandell & Smaldino, 2000a, b; Nelson & Soli, 2000; Picard & Bradley, 2001; Shield & Dockrell, 2003). In the classroom, children are exposed to many sound sources other than the target sound source (e.g., a teacher or classmate) they are asked to listen to. Children must separate all activities occurring in the classroom into separate sound sources by determining which acoustic components come from one or more sound sources. This process is known as sound source segregation (Bregman, 1990). Adults use various acoustic cues for sound source segregation (e.g., Bregman, 1990) but little is known about how infants and young children develop the ability to separate and select target words from unwanted sounds (Werner & Leibold, 2011). From the psycholinguistic perspective, little is known about how young children use a lexical representation cue (e.g., neighborhood density) in word learning in complex natural environments such as classrooms.

Among the many sources of noise in typical classrooms, heating, ventilating, and air-conditioning (HVAC) systems are considered to be the most significant noise source by the American Speech-Language-Hearing Association (ASHA, 2005) and the American National Standards Institute (ANSI, 2010) as well as many studies (Choi & McPherson, 2005; Nelson & Soli, 2000; Seep, Glosemeyer, Hulce, Linn, Aytar, & Coffeen, 2000; Siebein, 2004; Sutherland & Lubman, 2004). Many classrooms exceed the noise level recommended by ASHA (Crandell & Smaldino, 2000a; Flexer, 2004; Knecht, Nelson, Whitelaw, & Feth, 2002; Nelson, Kohnert, Sabur, & Shaw, 2005; Picard & Bradley, 2001; Sato & Bradley, 2008) even when the HVAC systems are turned off (Knecht, Nelson, Whitelaw, & Feth, 2002). Hence, children are constantly exposed to high ambient noise in classrooms.

For children to perceive speech accurately, the most crucial aspect to consider is the signal-to-noise ratio (SNR), which is defined as “the relationship between the intensity of the signal and the intensity of the background noise at the child’s ear” (Crandell & Smaldino, 2000a, p. 364). For example, if a speech signal is presented at 65dB and the noise is at 55dB, the SNR would be +10dB, indicating that the amplitude of the speech signal is greater than the amplitude of the noise by 10dB. The speech signal will be perceived twice as loud as the noise because

10dB increase in amplitude equals to doubling in loudness. Speech perception performance decreases as SNR becomes less favorable. The ASHA (2005) and the ANSI (2010) recommend greater than +15dB SNR for optimum communication. However, studies demonstrate large discrepancies between the recommended SNR (i.e., + 15dB) and the observed SNR (ranging from - 7 to +6 dB) in classrooms (Blair, 1977; Crandell, 1993; Finitzo-Hieber, 1988; Markides, 1986; Picard & Bradley, 2001). Furthermore, studies reveal that noise levels in occupied preschool classrooms are higher than those of occupied elementary schools (Picard & Boudreau, 1999; Sanders, 1965). Consequently, younger children, such as preschoolers, may experience more classroom noise than older children.

This noisy classroom environment may impact children's academic performance. Studies reveal a detrimental effect of noise on cognitive processes and academic performance in reading (Maxwell & Evans, 2000), mathematics (Cohen, Evans, Krantz, Stokols, & Kelly, 1981), attention (Crandell & Smaldino, 1996), speech intelligibility (Bradley, 1986), and memory (Heinrich, Schneider, & Craik, 2008). Given that children's vocabulary acquisition and development form a significant foundation of academic performance (Beck, McKeown, & Kucan, 2002) and vocabulary in younger children (i.e., preschoolers or kindergarten) becomes a significant predictor of reading comprehension and eventually academic success (Biemiller, 2005, 2006), it is imperative to investigate how noise may affect word learning, a process that involves word recognition and working memory in preschool-age children.

To date, few studies have directly examined word learning in noise. To make predictions about how noise may impact word learning, the broader literature on the impact of noise on language processing must be considered. The word recognition literature is relevant because of its relationship to the triggering process of word learning in which listeners identify whether an input word matches with a lexical representation in long-term memory. Likewise, the working memory literature is relevant because of its relationship to configuration in which listeners hold the phonological form of the novel word in working memory over a short period of time while also forming a lexical representation of the novel word in long-term memory.

The effect of noise on word recognition. Children generally perform poorly on spoken word recognition in noisy environments compared to a quiet environment (Crandell & Smaldino, 2000a, b; Finitzo-Hieber & Tillman, 1978; Nabelek & Nabelek, 1994). Children also show poorer performance than young adults on spoken word recognition in noise (Elliot, 1979; Nittrouer & Boothroyd, 1990; Stelmachowicz, Hoover, Lewis, Kortekaas, & Pittman, 2000). Interestingly, recognition performance is correlated with the age of children, with the youngest ones performing the poorest. For example, Elliott (1979) demonstrated that in noise, 9-year-old children recognized significantly fewer words than 11-year-old children, and 11- and 13-year olds recognized significantly fewer words than 15- and 17-year olds. In contrast, in the quiet condition, 11- and 17-year olds did not show any significant difference in recognition performance, implying no difference in linguistic knowledge between 11- and 17-year olds compared to 15- and 17-year olds. Unfortunately, no data were collected from 9-year olds in the quiet condition. Children as young as preschoolers (M = 5;6) also showed poorer recognition scores in noise than young adults in a study by Nittrouer and Boothroyd (1990). Similarly, 5- to 10-year-old children recognized fewer words at low audibility levels than young adults (Stelmachowicz et al., 2000). In contrast, children recognized almost all words at high audibility levels, similar to the performance of young adults (Stelmachowicz et al., 2000). Other studies show that children require higher SNRs than adults to achieve equivalent perception scores

(Crandell & Smaldino, 1994, 1995, 1996, 2000b; Crandell, Smaldino, & Flexer, 1995; Elliott, 1979; Elliott, Connors, Kille, Levin, Ball, & Katz, 1979; Nabeleck & Nabelek, 1994).

Taken together, these results indicate developmental differences between children and adults in dealing with speech information in noisy environments. Thus, word recognition in younger children may be more negatively influenced by noise than older children or adults, implying that younger children may have a difficulty in recognizing an input word as a novel or known word in the presence of noise, resulting in delayed triggering of word learning.

The effect of noise on working memory. Language processing in noise taxes the working memory system. For example, many studies show that performance of adults in recalling sentence-final words becomes poorer as the SNR worsens (Heinrich, et al., 2008; Pichora-Fuller, 2003a, b; Pichora-Fuller, Schneider, & Daneman, 1995; Rabbitt, 1968). It is hypothesized that the central executive in the working memory system allocates more attentional resources to auditory processing in noise to segregate the two auditory streams from one another (i.e., speech vs. noise). This leaves fewer available resources for cognitive processing, resulting in poor performance in recall. Young children have a limited working memory capacity compared to older children and adults. In particular, working memory span increases dramatically from 4 years of age to 8 years of age and continues to increase, albeit less dramatically, from 8 to 16 years of age (Gathercole, 1998, 1999). Thus, the working memory literature also suggests that noise will be particularly challenging for younger children because their working memory is still developing. This implies that young children may have difficulty holding the phonological form of a novel word in working memory, resulting in delayed configuration of new lexical representations and/or configuration of less detailed or fragile lexical representations.

The effect of noise on word learning. Very few studies have been published on the effect of noise on word learning. A recent study investigated word recognition, delayed word repetition, and word learning in quiet and noisy listening conditions with 9- to 10-year-old children as participants (Riley, 2010). This study used broadband white noise to mimic the noise from the HVAC systems. For word recognition, children were asked to repeat a novel word immediately after the word was aurally presented under one of seven SNRs (i.e., ±8, ±6, ±2, and 0 dB). In the delayed word repetition, the auditory stimulus was accompanied by a corresponding visual referent on the computer screen. Then, the picture appeared again and the child was asked to name it under the same seven SNRs. In the word learning task, children were randomly assigned to either a quiet (no noise) or a noisy condition (i.e., +8 dB SNR). Children in both conditions were presented with 16 consonant-vowel-consonant novel words with corresponding novel object referents embedded in stories. Each novel word was presented 13 times in the entire stage. In this study, the children's word recognition performance showed 100% accuracy across all SNRs. In contrast, children's delayed word repetition performance became worse as SNR worsened. For word learning, children in the quiet condition named more words accurately than children in the noisy condition. Thus, background noise interfered with delayed word repetition and word learning in school-aged children.

Riley interpreted these results to indicate that children were able to encode phonological forms of novel words completely correctly regardless of noise during the recognition task. However, noise interfered with children's ability to retain the phonological form in working memory long enough to recall the word correctly in the delayed word repetition task. Furthermore, these noise effects persisted in the word learning task despite multiple exposures to the item. Thus, this study demonstrates that noise interferes with 9- to 10-year-old children's ability to retain newly heard lexical items within working memory, resulting in difficulty constructing new lexical representations and/or difficulty refining representations even with repeated exposures. Based on the results of Riley's study, noise may not interfere with triggering of word learning but may interfere with the configuration process of word learning.

The effect of noise on neighborhood density effects. Little research has been conducted on the effect of noise on neighborhood density effects. Recently, Taler, Aaron, Steinmetz, and Pisoni (2010) investigated adult spoken word recognition at two SNRs (i.e., +10 dB and -3 dB) in a sentence repetition task in which each sentence contained three keywords from dense or sparse neighborhoods. The results were consistent with those from the previous spoken word recognition studies. That is, adults recognized words in sparse neighborhoods more accurately and quickly than words in dense neighborhoods. Also, recognition accuracy was higher at +10 dB SNR than at -3 dB SNR. More importantly, the magnitude of the neighborhood density effect on recognition was greater in the challenging listening condition (-3 dB SNR) than in the favorable listening condition (+10 dB SNR). These results suggest that noise may amplify the effects of neighborhood density. Thus, a stronger influence of density on word learning may be observed in noisy conditions.

Research Questions

The overarching goal of this study was to investigate how noise affects the ability to learn novel words in preschool children. This study primarily examined whether noise alters the effect of neighborhood density on word learning in preschool children. The research questions and the predictions for each question are as follows:

(1) Does noise negatively influence word learning in preschool children? It was predicted that noise would negatively influence word learning performance. This prediction was based on Riley (2010) study which revealed that school-aged children had difficulties in retaining newly heard lexical items within working memory and in constructing new lexical representations in long-term memory when learning in a noisy environment. Moreover, preschool children showed poorer performance on word retrieval tasks in noise than school-aged children (Nittrouer & Boothroyd, 1990; Stelmachowicz et al., 2000). Thus, it is likely that the preschool children in the current study will be more sensitive to the effects of noise on word learning than the school-age children in Riley (2010). Word learning is predicted to be the best in the recommended +15dB SNR condition, followed by the realistic +6 dB SNR, and followed by the unfavorable 0 dB SNR condition. This result would help support the ASHA recommended standards.

(2) What is the relationship between density and noise in word learning by preschool children? This question addresses the potential interaction between density and noise during word learning. If significant, the interaction could be described in one of two ways: The effect of density at +15, +6, and 0dB SNRs; and the effect of noise for low vs. high density. First, it was predicted that the effect of neighborhood density on word learning in a quiet condition (Storkel, 2009; Storkel et al., 2006; Storkel & Lee, 2011) would be observed in noise. This would be consistent with the findings from studies on word recognition showing that noise amplifies the neighborhood density effect (Taler, et al., 2010). Specifically, the difference between sparse and dense neighborhoods would increase as the SNR worsens. Thus, the largest difference in the density effect would be observed at 0dB SNR, followed by +6dB SNR, and followed by +15dB SNR. This prediction implies that as a listening condition worsens, young children might rely more on existing lexical representations. Second, it was predicted that regardless of whether novel words are in spars or dense neighborhoods, word learning would improve as SNR improves. Based on the first prediction, it was predicted that the magnitude of the noise effect would be significant between +15 and 0dB SNRs for low density words. This prediction implies that learning low density words might be sensitive to listening conditions.

(3) Does the effect of neighborhood density change over time during word learning by preschool children? Storkel and Lee (2011) provided evidence that sparse neighborhoods facilitated triggering of word learning at early test points whereas dense neighborhood facilitated configuration and engagement at later test points. The current study provided an opportunity to replicate this finding over a longer time span with three more cycles of training-testing and one more no-training point.

(4) Does noise influence children's performance on production and comprehension tasks of word learning? As in Riley (2010), it was predicted that noise would have an influence on word learning when measured by a production task but not when measured by a comprehension task given the lack of an effect of noise on word recognition in her study. However, it would be possible that noise would influence performance on both tasks for these younger children. This alternative prediction was based on existing studies on recognition (Elliot, 1979; Finitzo-Hieber & Tillman, 1978; Nittrouer & Boothroyd, 1990; Stelmachowicz et al., 2000) where developmental differences between children and adults were observed in the effect of noise. Thus, preschool-aged children might be more susceptible to noise in spoken word recognition than school-aged children. Consequently, preschool-age children's performance scores on both production and comprehension tasks might decline as the SNR worsens.

Method

Participants

Table 1 represents participant characteristics.

Table 1

Mean, SD, and Range of Participant Characteristics

	0dB SNR (n = 27)	+6dB SNR (n = 24)	+15dB SNR (n = 26)
Age	4;8 (0;5) 4;1-5;3	4;9 (0;5) 4;1-5;4	4;9 (0;5) 4;0-5;6
GFTA-2 SS[a]	110 (8) 94-122	113 (5) 102-119	113 (4) 103-121
EVT-2 SS[b]	117 (10) 97-136	116 (11) 100-136	114 (10) 96-131
PPVT-4 SS[c]	120 (12) 101-147	118 (10) 96-133	114 (11) 92-139

[a] Standard Scores on the *Goldman-Fristoe Test of Articulation-2* (Goldman & Fristoe, 2000)
[b] Standard Scores on the *Expressive Vocabulary Test-2* (Williams, 1997)
[c] Standard Scores on the *Peabody Picture Vocabulary Test-4* (Dunne & Dunn, 1997)

Seventy-seven typically developing preschool children participated in this study. Children were recruited from the following cities in Kansas: Lawrence, Kansas City, and Topeka. Participants were 38 females and 39 males whose mean age was 4;9 (*Range*: 4;0 – 5;6; *SD*: 8 months). All participants met the following inclusion criteria: (1) native speakers of American English from monolingual families; (2) no cognitive, social, emotional, motor, visual, hearing, or major medical impairments as reported by parents; (3) normal hearing as determined by a standard screening (ASHA, 1997); and (4) normal articulation, expressive vocabulary, and receptive vocabulary (i.e., a score at or above the 16th percentile or a standard score of 85) as verified by the Goldman-Fristoe Test of Articulation-2 (GFTA-2; Goldman & Fristoe, 2000), the Expressive Vocabulary Test-2 (EVT-2; Williams, 1997), and the Peabody Picture Vocabulary Test-4 (PPVT-4; Dunn & Dunn, 1997). The children were randomly divided into three groups, and each group was assigned to one of three listening conditions: 0dB SNR, +6dB SNR, and +15dB SNR (see rationale below).

Materials

Nonword stimuli consisted of 16 consonant-vowel-consonant (CVC) nonwords which were selected from the corpus developed by Storkel (2013). The corpus consists of 687 CVC nonwords that are made up of early acquired consonants (i.e., m, n, p, b, t, d, k, g, f, w, j, and h). The nonwords do not appear in a 20,000 word adult corpus (Nusbaum, Pisoni, & Davis, 1984) or a 5,000 word child corpus (Storkel & Hoover, 2010b). Specifically, this nonword corpus was developed by generating all legal CVC, and then excluding (1) real words from other corpus, (2) r-coloring vowels (i.e., ɝ and ɚ), and (3) any CVC sequences with a biphone sum of 0 and neighborhood density of 0. Phonotactic probability (the probability of the occurrence of individual sounds and sound sequences in a given language) and neighborhood density for the 687 CVC nonwords were calculated based on the adult and the child corpus. For the current study, to investigate the independent effect of neighborhood density on word learning, the nonwords to be learned differed in neighborhood density (i.e., dense vs. sparse) while phonotactic probability was held constant.

Phonotactic probability. Phonotactic probability is a characteristic of phonological representations (Jusczyk, Luce, & Charles-Luce, 1994). Two measures of phonotactic probability were computed using the adult and the child corpus: Positional segment sum and biphone sum (Storkel, 2004b). Positional segment sum is the sum of the positional segment frequencies of individual sound in the word. Positional segment frequency is calculated by adding the log frequency of each word in the corpus that contains the target sound in the target word position (e.g., /w/ in the first position in the word /wɔʧ/) and dividing by the sum of the log frequency of every word in the corpus that contains any sound in the target word position (e.g., first word position) (Storkel, 2004b). Thus, positional segment sum is, for example, the sum of positional segment frequency of /w/, /ɔ/, and /ʧ/ in the word /wɔʧ/.

Biphone sum is the sum of the biphone frequencies of each adjacent pair of sounds in the word. Biphone frequency is calculated by adding the log frequency of each word in the corpus that contains the target pair of sounds in the target word position (e.g., /wɔ/in the first word position in the word /wɔʧ/) and then dividing by the sum of the log frequency of every word in the corpus that contains any sound in the target word position (e.g., first word position) (Storkel, 2004b). Thus, biphone sum is, for example, the sum of biphone frequency of /wɔ/ and /ɔʧ/in the word /wɔʧ/.

For this study, as Storkel & Lee (2011) computed, phonotactic probability was held essentially constant at a mid-level of positional segment sum and biphone sum (i.e., 50th percentile ± ½ SD) to examine the independent effect of neighborhood density.

Neighborhood density. Neighborhood density is computed by counting the number of words in the adult or child corpus that differ from a given nonword by a one-phoneme addition, deletion, or substitution. For example, the neighbors of /wɔʧ/ are /wɪʧ, wɔk, wɔl, wɔʃ, wɔr/ based on this one-phoneme difference. In total, /wɔʧ/ has five neighbors. Thus, the density of /wɔʧ/ is five. For this study, as Storkel & Lee (2011) defined, words ranking in the 10th-25th percentile for neighborhood density in the nonword corpus were defined as sparse and words in the 50th-75th percentile for neighborhood density in the nonword corpus were defined as dense. The selected

Table 2

Characteristics of the Stimuli

	Sparse [a]	*Dense* [b]
Characteristics based on adult corpus		
Positional segment sum		
M	0.12	0.12
(*SD*)	(0.01)	(0.01)
Range	0.11-0.14	0.11-0.14
	t (14) = .23, *p* = .82, *d* [c] = 0	
Biphone sum		
M	0.003	0.003
(*SD*)	(0.001)	0.001
Range	0.002-0.004	0.003-0.004
	t (14) = .00, *p* = 1.00, *d* = 0	
Neighborhood denstiy		
M	9	16
(*SD*)	(1)	(2)
Range	6-10	13-18
	t (14) = 8.84, *p* < .05, *d* = 4.43	
Characteristics based on child corpus		
Positional segment sum		
M	0.13	0.13
(*SD*)	(0.01)	(0.01)
Range	0.11-0.14	0.13-0.15
	t (14) = .95, *p* = .36, *d* = 0	
Biphone sum		
M	0.004	0.004
(*SD*)	(0.001)	(0.001)
Range	0.003-0.005	0.003-0.005
	t (14) = .91, *p* = .38, *d* = 0	
Neighborhood denstiy		
M	5	10
(*SD*)	(2)	(1)
Range	3-7	9-11
	t (11.13) = 8.50, *p* < .05, *d* = 3.16	

Consonant confusion (%)		
Initial position		
M	56	54
(*SD*)	(12)	(13)
Range	45-71	48-71
	$t(14) = .37, p = .72, d = .19$	
Final position		
M	50	54
(*SD*)	(6)	(4)
Range	43-61	47-61
	$t(14) = 1.34, p = .20, d = -.67$	

Note. [a]/gɛp wæb fag mib haf jɪg maɪb fup/
[b]/boʊg fip mum naɪk peɪg paɪf wap jʌt/
[c] effect size: $d = 0.3$ small
= 0.5 medium
= 0.8 large

nonwords were eight nonwords from sparse neighborhoods and eight nonwords from dense neighborhoods with matching phonotactic probabilities. Thus, neighborhood density varied, but the average positional segment sum and biphone sum values were comparable. Table 2 presents the values for the selected CVCs obtained from both the adult and the child corpus.

Consonant confusion. Listeners may confuse speech sounds with other similar ones in the presence of noise (Phatak, & Allen, 2007), resulting in inaccurate consonant identification that is consequently misinterpreted as another consonant (Phatak, Lovitt, & Allen, 2008). This study employed the consonant matrix from Wang and Bilger (1973) to examine consonant confusion of nonwords varying in neighborhood density. Wang and Bilger's (1973) consonant matrix consisted of 24 CV and 24 VC syllables in combination of 16 consonants and three vowels presented with white noise at six SNRs (i.e., -10, -5, 0, +5, +10, and +15dB SNRs). Although they obtained the consonant matrixes for each syllable by adding consonant confusions across all SNRs, not at one specific SNR, these consonant matrixes still provide an idea of the likelihood a given speech sound is perceived accurately or potentially confused with a similar speech sound. For this study, the goal was to control confusability across sparse and dense neighborhoods.

In the current study, consonant confusions were calculated based on Wang and Bilger's (1973) consonant matrixes. For example, consonant confusion of 55% for *p* in the nonword *peɪg* means that for 55% of responses, the consonant *p* is reportedly heard as *p* in the first consonant position in the nonword *peɪg*. Consonant confusions for the stimulus consonant used in this study are presented in Appendix A and summarized in Table 2. Overall, no significant differences in the consonant confusions were found between sparse and dense neighborhoods for the first consonants in the CV syllable [$t(14) = .37$, $p = .72$, $d = .19$] and the second consonants in the VC syllable [$t(14) = 1.34$, $p = .20$, $d = -.67$], demonstrating consonant confusion being controlled.

Novel Object Referents

The selected nonwords were paired with pictures of novel objects. This study used the same novel object referents that had been used for preschool children in Hoover et al. (2010), and Storkel (2004a) and for adults in Storkel et al. (2006). Some of these novel objects were adapted from children's stories and others were fabricated so that they do not have representations in the real world. The 16 novel object referents came from four semantic categories: Candy machine, toy, horn, and pet. Each semantic category consisted of four novel object referents (e.g., Candy machine with four novel object referents: Red, Blue, Yellow, and Green Candies), among which two novel object referents (e.g., Red and Yellow candies) were paired with two nonwords from sparse neighborhoods and the other two novel object referents (e.g., Blue and Green candies) were paired with nonwords from dense neighborhoods. Table 3

Table 3

The Examples of Nonword-Novel Object Pairs from Semantic Category in Neighborhood Density

Neighborhood Density		Semantic Category	Referent 1	Referent 2	Referent 3	Referent 4
Sparse	Dense					
gɛp	**boʊg**	Candy machine	**Red circle candy**[a]	**Blue star candy**[a]		
haf	*peɪg*				*Blue triangle candy*[a]	*Orange rectangle candy*[a]
wæb	**fip**	Toy	**Gun toy with string**[b]	**Punch toy with spring**[b]		
jɪg	*paɪf*				*Flying arrow*[b]	*Shooting gas*[b]
fag	**mum**	Horn	**Yelow looped horn**[b]	**Red snake horn**[b]		
maɪb	*wap*				*Red s-shaped horn*[b]	*Blue straight horn*[b]
mib	**naɪk**	Pet	**Green caterpillar**[c]	**Blue armadillo**[d]		
fup	*jʌt*				*Red elephant*[d]	*Yellow bat*[d]

Note . Referents 1 and 3 were paired with words in sparse neighborhood and Referents 2 and 4 were paired with words in dense deighborhood density.

Nonword-novel object pairs in bold were presented in Story 1. Nonword-novel object pairs in italic were presented in Story 2.

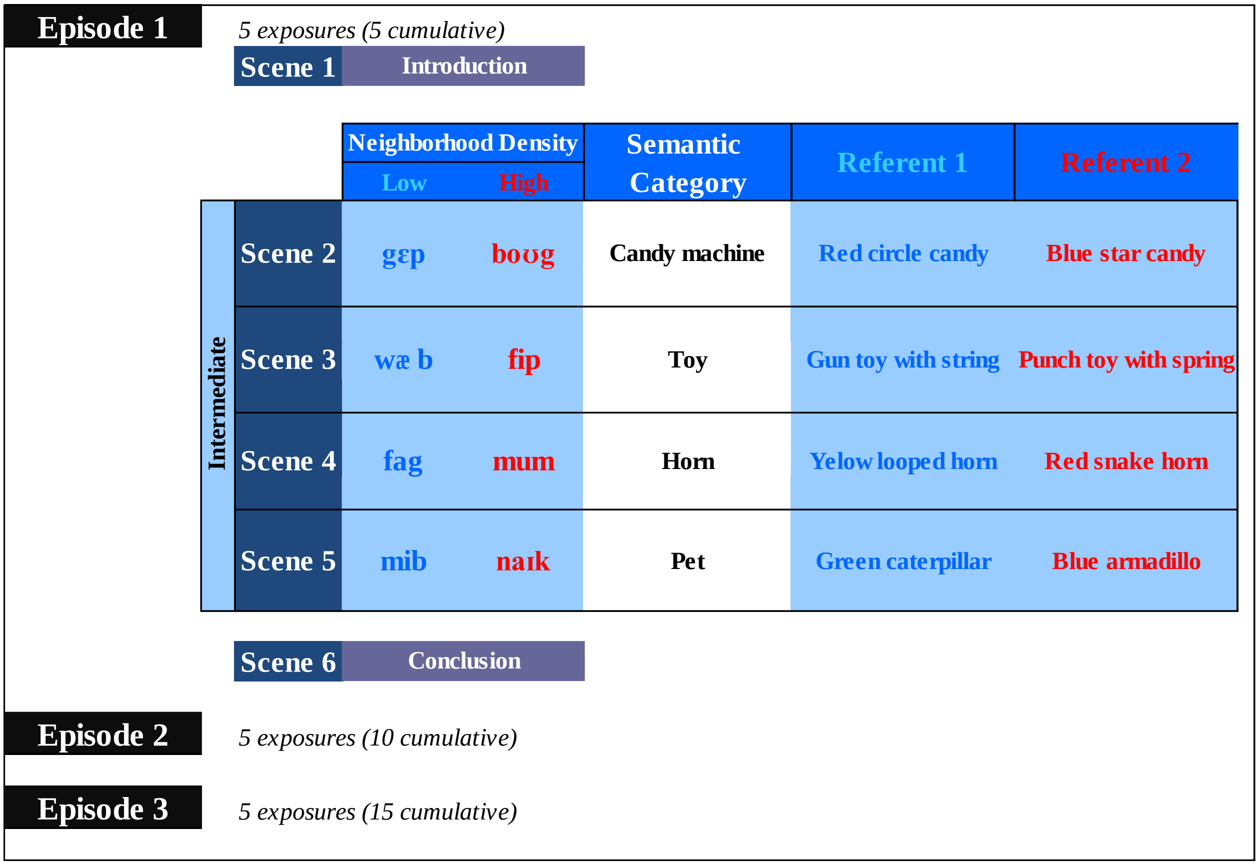
[a]Storkel, et al. (2006); [b]Geisel & Geisel (1958); [c]DeBrunhoff (1981); [d]Mayer (1992).

presents an example of pairing novel object Referents 1 and 3 with nonwords from sparse neighborhoods and novel object Referents 2 and 4 with nonwords from dense neighborhoods.

Stories

This study used the same stories as those used in Hoover, Storkel, and Hogan (2010) and Storkel, et al. (2006); however, the script and the number of presentations for each story were adjusted to increase the number of exposures to each nonword in order to guard against floor effects in children especially in noise. Two stories with the same format were used to present participating children with the 16 nonword-novel object pairs. Each story contained eight nonwords, among which four words were from sparse neighborhoods and four words were from dense neighborhoods. Four versions of each of two stories were created to counterbalance nonword-novel object pairs across participants. One of the four story versions is seen in Table 3 in which the nonwords in bold and novel object referents 1 and 2 were embedded in Story 1. Nonwords in italic and novel object referents 3 and 4 were embedded in Story 2.

Each story consisted of three distinct episodes, as seen in Figure 1. Each episode contained six visual scenes and corresponding auditory narratives. The first scene was an introduction to two main characters and one main activity (e.g., boy and girl characters going to a park with objects). The next four succeeding intermediate scenes provided exposures to the eight nonword-novel object referent pairs. A nonword in a sparse neighborhood and a nonword in a dense neighborhood from the same semantic category were introduced in a particular intermediate scene. For example, in Figure 1, in Scene 2, the nonword /gɛp/ in a sparse neighborhood paired with the novel object of Red candy machine was presented along with the nonword /boʊg/ in a dense neighborhood paired with the novel object of Blue candy machine from the same semantic category of Candy machine. Each nonword was presented five times in a



Episode 1 *5 exposures (5 cumulative)*

Scene 1 Introduction

		Neighborhood Density		Semantic Category	Referent 1	Referent 2
		Low	High			
Intermediate	Scene 2	gɛp	boʊg	Candy machine	Red circle candy	Blue star candy
	Scene 3	wæ b	fip	Toy	Gun toy with string	Punch toy with spring
	Scene 4	fag	mum	Horn	Yelow looped horn	Red snake horn
	Scene 5	mib	naɪk	Pet	Green caterpillar	Blue armadillo

Scene 6 Conclusion

Episode 2 *5 exposures (10 cumulative)*

Episode 3 *5 exposures (15 cumulative)*

Figure 1. Episode constituents in a story. The same nonword-novel object referent pairs were presented across episodes in a story. However, the order of presentation of the intermediate scenes was randomized across participants.

particular intermediate scene (e.g., Boy thinking about red candy machine along with the narrative scripts presenting “Big Brother's favorite candy was from the /gɛp/. He ran to the /gɛp/. He got candy from the /gɛp/. He stuffed all the candy from the /gɛp/ in his mouth. The candy from the /gɛp/ was really good.”). The story narratives for two main characters were the same except for the embedded target words. The order of the presentation of the intermediate scenes in each episode was randomized across participants. Following four intermediate scenes, the last scene was a conclusion of the main activity. The same main characters and nonword-novel object pairs appeared across three episodes in a story, but the main activity changed across episodes (e.g., going to the park with objects in Episode 1; competing against each other using objects in Episode 2; and playing hide-and-seek with objects in Episode 3). The order of the presentation for Story 1 and Story 2 was randomized along with four alternative versions for each story being used to counterbalance nonword-novel object. A sample story episode is in Appendix B.

All visual scenes were digitized and edited. A female talker who was a 21-year-old native speaker of American English produced the nonwords and audio narrative script. Productions were recorded digitally at a resolution of 16 bits and a sampling rate of 44.1 kHz in a sound-treated booth at the University of Kansas, using a Marantz PMD671 recorder and Shure SM-10 microphone. Recordings were edited using the CSL4500 speech analysis system. The speaking rate of the nonwords and the narrative script, as measured in syllables per second using a spectrogram, was not significantly different across the neighborhood density conditions. Two judges listened to the recorded stimuli in a quiet condition and transcribed each stimulus to verify the quality of the recording. Both judges found that all target words and narrative scripts were recorded as intended.

Signal-to-Noise Ratios

Once the nonword stimuli and audio narrative scripts were digitally recorded and edited, they were digitally mixed with broadband white noise using MATLAB (The Mathworks, Version 8.4) to generate the three SNRs (i.e., 0dB, +6dB, and +15dB SNRs) for this study. The speech signal was kept at 65dB SPL as a presentation level and the noise was scaled for each SNR. Specifically, for 0dB SNR, both speech signal and noise were at 65dB SPL; for +6dB SNR, the speech signal was kept at 65dB SPL and the noise was scaled to 59dB SPL; and for

+15dB SNR, the speech signal was kept at 65dB SPL and the noise was scaled to 50dB SPL by following the steps:

(1) The standard deviation of the speech signal was determined;

(2) The speech signal was divided by the standard deviation;

(3) The speech signal was then divided by the maximum intensity of the signal in order to prevent any intensity clipping;

(4) The different SNRs were generated by using the following equation for dB SPL:

$$SNR_{dB} = 20 \log_{10}(X)$$

(5) Stimuli were saved as wav files.

A 0.5 second of silence was digitally added to both the beginning and end of the nonword and narrative script to prevent the preceding stimuli from masking the following stimuli. Broadband white noise was selected to mimic the typical noise in an average classroom. This was based on the fact that the ASHA (2005) and the ANSI (2010) identified heating, ventilating, and air conditioning (HVAC) systems as the most significant noise source and the characteristic of noise from the HVAC systems is similar to that of broadband white noise.

Among the selected three SNRs, ***0dB SNR***, one of the commonly reported classroom SNRs (Bess, 1985; Blair, 1977; Finitzo-Hieber & Tillman, 1978), means the same loudness in the speech signal and the noise. It served as an ***unfavorable listening condition*** for this study. The SNR of ***+6dB***, one of the commonly reported classroom SNRs (Bess, 1985; Blair, 1977; Crandell, 1993; Finitzo-Hieber & Tillman, 1978), means that the speech signal is 1.5 (2^0.6) times louder than the noise. It served as a ***realistic listening condition*** for this study. The SNR of ***+15dB*** means that the speech signal is 2.8 (2^1.5) times louder than the noise. This level is the minimal optimal SNR recommended by the ASHA (2005) and the ANSI (2010) for an optimal classroom environment. Thus, this study investigated word learning by preschool children in this ***recommended listening environment***.

Measures of Learning

Learning was measured using a picture naming task and a referent identification task. The naming task was intended to test children's production ability. In the naming task, children were shown a picture of one of the novel object referents on the computer screen and were asked to name the nonword. Note that in both the picture naming task and the referent identification task, the instructions were provided by an examiner in a quiet condition (i.e., not in any of the SNR conditions) to ensure that children understood the tasks. Responses were audio and video recorded, phonetically transcribed, and scored as correct if all three phonemes were named correctly in the correct word position.

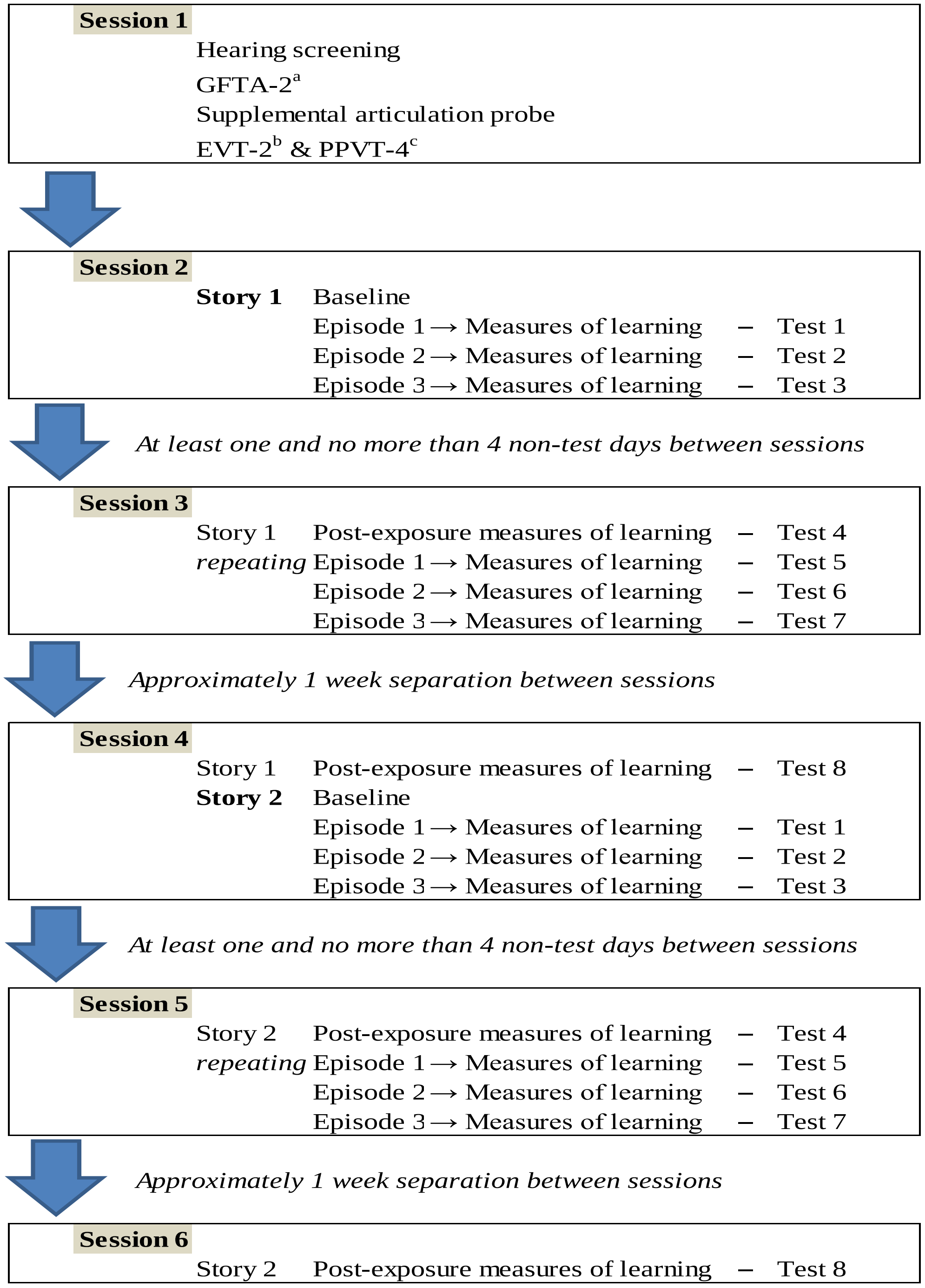
The referent identification task was intended to test children's comprehension ability. In the referent identification task with a word recognition format, eight pictures of the novel objects presented in the story appeared on the computer screen in two rows of four novel objects with a number right below each picture. After children heard a pre-recorded nonword in an assigned SNR condition, children were asked in a quiet condition to select one picture that corresponded to the nonword that they had heard. The number of the picture selected by the children was recorded on a response sheet and also entered on the number pad connected to the computer. A response was scored as correct if the correct novel object was selected. The order of the picture alternatives was randomized across trials.

Because the referent identification task could facilitate performance on the naming task, the naming task was always administered first, followed by the referent identification task. Both tasks were administered (1) prior to a story to obtain a baseline, (2) immediately after each episode, and (3) at post-exposure to nonwords to obtain retention of learning. For each task, the proportion of correct responses to nonwords served as the dependent variable for analysis.

Procedure

Immediately prior to the start of each session, the presentation level of the stimulus (i.e., 65dB SPL) was confirmed using a sound level meter. The sound level meter was set range to 70 dB because each range covered 20dB (i.e., 60 to 80dB), and 70dB was the closest to the presentation level of 65dB. Thus, the sound level meter measured sound levels from 60 to 80 dB and displayed the average sound level within the range. The presentation level of 65dB SPL was confirmed if the sound level meter provided approximate average sound level of 65dB. ‘A’ weighting was selected for environmental measurements with SLOW measurement mode. The sound level meter was placed where participants were seated approximately 15 inches away from the center of the computer screen and at 45-degree angle from the external speakers that were placed on the sides of the computer. The microphone of the sound level meter was pointed to the computer screen to measure a presentation level of the stimuli at child’s seat. An episode was randomly selected across stories to check the presentation level. Children’s responses were recorded via a head-mounted microphone on audio and video recorders. The presentation of visual and auditory stimuli was controlled by DirectRT software (Jarvis, 2002). The experimental procedures are shown in Figure 2.

The study required six sessions that consisted of one 45-minute session for screening, four 30-minute sessions for word learning and the first retention/gap, and one 10-minute session for the second retention/gap. In the first session, as seen in Figure 2, the child’s hearing was screened following the procedures recommended by the ASHA (1997). The child’s articulation



Session 1
Hearing screening
GFTA-2[a]
Supplemental articulation probe
EVT-2[b] & PPVT-4[c]

Session 2
Story 1 Baseline
Episode 1 → Measures of learning – Test 1
Episode 2 → Measures of learning – Test 2
Episode 3 → Measures of learning – Test 3

At least one and no more than 4 non-test days between sessions

Session 3
Story 1 Post-exposure measures of learning – Test 4
repeating Episode 1 → Measures of learning – Test 5
Episode 2 → Measures of learning – Test 6
Episode 3 → Measures of learning – Test 7

Approximately 1 week separation between sessions

Session 4
Story 1 Post-exposure measures of learning – Test 8
Story 2 Baseline
Episode 1 → Measures of learning – Test 1
Episode 2 → Measures of learning – Test 2
Episode 3 → Measures of learning – Test 3

At least one and no more than 4 non-test days between sessions

Session 5
Story 2 Post-exposure measures of learning – Test 4
repeating Episode 1 → Measures of learning – Test 5
Episode 2 → Measures of learning – Test 6
Episode 3 → Measures of learning – Test 7

Approximately 1 week separation between sessions

Session 6
Story 2 Post-exposure measures of learning – Test 8

Figure 2. Flow of Experimental Procedures. The order of the presentation for Story 1 and Story 2 was randomized. [a]Goldman-Fristoe Test of Articulation-2 (Goldman & Fristoe, 2000). [b]Expressive Vocabulary Test-2 (Williams, 1997). [c]Peabody Picture Vocabulary Test-4 (Dunne & Dunn, 1997).

was screened using the GFTA-2 (Goldman & Fristoe, 2000) and a supplemental articulation probe for the target consonants used in the nonwords. Next, the receptive and expressive vocabulary tests were administered using the Peabody Picture Vocabulary Test-4 (Dunn & Dunn, 1997) and the Expressive Vocabulary Test-2 (Williams, 1997), respectively.

In the second session, as seen in Figure 2, prior to the presentation of a story, the naming task and the referent identification task were administered in the assigned noise condition to obtain a baseline for each nonword from the first story. In the naming task, children were told that they would see pictures of objects on the laptop computer screen that they had never seen before and would be asked to guess the names of the pictures. A picture of each novel object was presented one by one. Following the baseline measures, the first episode of the story was presented in the assigned SNR condition. Following each story episode, learning of the nonword-novel object referent pairs was measured via the picture naming task and referent identification task.

In the third session, as seen in Figure 2, the series of Episodes 1, 2, and 3 and measures of learning for each episode for the first story were repeated to provide more exposures to nonwords to-be-learned so that children were exposed to each nonword 30 times by the end of a story (i.e., six episodes per story with five times of exposure in each episode).

The fourth session was conducted approximately one week after the third session as seen in Figure 2. Learning of the nonword-novel object referent pairs from the first story was measured via the naming task and the referent identification task in the assigned SNR condition. Then, baseline measures of learning for the second story were initiated in the assigned SNR condition. Following baseline measures, the procedures for the second story were the same as those for the first story. That is, Episodes 1, 2, and 3 for the second story were presented in the assigned SNR condition with measures of learning via the naming task and referent identification task following each episode.

In the fifth session, as seen in Figure 2, Episodes 1, 2, and 3 from the second story were repeated with measures of learning via the naming task and referent identification task following each episode. As with Story 1, 30 total exposures accumulated for each nonword in Story 2.

The sixth session was conducted approximately one week after the fifth session, as seen in Figure 2. Learning of the nonwords-novel object referent pairs from the second story was measured via the naming task and the referent identification task in the assigned SNR condition.

Reliability

Transcription reliability was computed for 18% of the participants for both nonword productions made during the word learning protocol and real word productions made on the GFTA-2 and supplemental probe. Mean percent agreement was 99% (*SD* = 0.01%, range 97% - 100%). Scoring reliability was computed for 15% of the participants for scoring the child's production against the target nonword and for coding the child's response as either correct or incorrect. Mean percent agreement was 100% (*SD* = 0%, range 100% - 100%). Procedural reliabilities were computed for 18% of the participants for correct administration (e.g., appropriate SNR administered, correct story versions selected, and story and item instructions read) and correct equipment function (e.g., all target items presented without computer malfunction). Mean percent agreement was 100% (*SD* = 0.5%, range 98% - 100%).

Analysis Approach

For data analysis, multilevel modeling (MLM) was used to analyze time-varying repeatedly observed responses to target items. MLM captures dependency across observations via random effects and estimates independent variables via fixed effects. Also, MLM accommodates unbalanced and missing data because it does not require same the data structure for each participant. In addition, MLM can include categorical and/or continuous predictors at any level. (Cnaan, Laird, & Slasor, 1997; Hoffman & Rovine, 2007; Misangyi, Lepine, Algina, & Goeddeke, 2006; Quene & van den Bergh, 2004). Since the dependent variable, accuracy (i.e., correct vs. incorrect), was a binary variable, a logistic MLM was used. Random intercepts for participants and target items were crossed at the same level. Fixed effects were age, vocabulary scores, neighborhood density, noise, time, the interactions of neighborhood density and noise, and neighborhood density and time.

In the current study, the variable of task consisted of two tasks that were used to measure word learning: A picture naming task and a referent identification task. The picture naming task was used to measure children's performance on production in an open-set format whereas the referent identification task was used to measure children's performance on comprehension in a closed-set format. The picture naming task may tap children's ability to retrieve words whereas the referent identification may tap children's ability to recognize words. Thus, in the current study, the variable of task was not treated as only one measure. Instead, the variable of task was treated as two outcome measures and each measure was included in the models separately, resulting in constructing two separate models by task. If variables were involved in the research questions but showed non-significant effects in either the naming task or the referent identification task, the variables were retained in the subsequent models for both tasks so that comparison of their effects in the two tasks was made. A total of 9660 observations were nested in 77 individuals in the naming task while a total of 9656 observations were nested in 77 individuals in the referent identification task.

Analysis Models

In the current study, seven models were additively built separately by task to address the research questions. Each model is shown in Appendices C and D. The seven models were as follows:

The first model was to examine the significance and magnitude of individual differences by entering the random effects of participants and test items with no fixed effects. The second model was to investigate the significance and magnitude of children's existing knowledge of vocabulary by adding the fixed effects of age, the EVT raw scores, and the PPVT raw scores. Only age and the EVT raw scores were retained in the subsequent models because: (1) age and vocabulary raw scores were positively correlated regardless of non-significant effect of age; (2) the effect of the EVT scores stayed significant in the subsequent models; and (3) the effect of the PPVT raw scores was not significant, resulting in the removal of this variable from the subsequent models. The third model added neighborhood density which is of primary interest in the current study and is involved in the research questions relevant to the interactions of density and noise, and density and time.

The fourth model added two time parameters, All Tests Slope and Gap, as study design parameters. The current study was designed to examine word learning at different points so that these time parameters have to be in the model. The current study employed the analysis format in Storkel, Bontempo, and Pak (2014) for these time parameters. In terms of input (see Figure 2), Tests 1-3 and Tests 5-7 were designed to measure word learning when input was presented while Test 4 and Test 8 were designed to measure word learning when the input was not presented. In terms of test intervals (see Figure 2), each test in Tests 1-3, and 4-7 occurred immediately following each Episode during training and approximately 10 minutes between tests. On the other hand, there was approximately a one-to-three-day gap between Tests 3 and 4, approximately a one-week gap between Tests 7 and 8. Therefore, the current study included two study design characteristics: (1) some tests (Tests 1-3 and Tests 5-7) represented word learning with input and others (Tests 4 and 8) represented word learning without input, during gaps in training; and (2) the test interval between adjacent tests was not consistent. To capture these two characteristics of study design, the two parameters, All Tests Slope and Gap, were included in the models. The parameter All Tests Slope represented linear growth of learning across tests while the parameter Gap represented any off-set from the linear growth. The off-set from the linear growth can have different directions. That is, this parameter can be in a positive direction, indicating memory consolidation (remembering). Or, this parameter can be in a negative direction, indicating forgetting of newly learned words.

The fifth model added three types of noise (0dB SNR, +6dB SNR, and +15dB SNR) to address the research question: Does noise negatively influence word learning in preschool children? The sixth model added the interaction of density and noise to address the research question: What is the relationship between density and noise in word learning by preschool children? The seventh model added the interaction of density and time to address the research question: Does the effect of density change over time during word learning by preschool children?

Results

Table 4 shows the final model with the parameter estimates for random effects and fixed effects by task.

Participant and Item Effects

In the naming task, the random effects of participants and items were significant,

Table 4

Final Multi-level Model

	Naming							Referent Identification						
Parameter	Estimate	*SE*	LCL	UCL	*OR*	*t*	*p*	Estimate	*SE*	LCL	UCL	*OR*	*t*	*p*
Intercept	-4.80	0.29				-16.53	<.0001	-1.96	0.18				-10.81	<.0001
Age	0.04	0.03	0.99	1.10	1.04	1.57	0.12	0.01	0.02	0.97	1.04	1.01	0.41	0.68
EVT	0.03	0.01	1.01	1.06	1.03	2.74	0.01	0.02	0.01	1.01	1.04	1.02	3.13	0.00
Neighborhood Density	-0.09	0.07	0.79	1.06	0.91	-1.23	0.23	-0.01	0.05	0.91	1.09	0.99	-0.15	0.88
All Tests Slope	0.36	0.02	1.37	1.50	1.43	14.96	<.0001	0.18	0.01	1.17	1.23	1.20	14.91	<.0001
Gap^a	-1.05	0.13	0.30	0.47	0.37	-8.29	<.0001	-0.09	0.06	0.81	1.03	0.92	-1.45	0.15
6dB SNR^b	0.63	0.29	1.05	3.33	1.87	2.13	0.04	0.22	0.18	0.87	1.79	1.25	1.21	0.23
15dB SNR^b	0.44	0.29	0.88	2.77	1.56	1.52	0.13	0.17	0.18	0.83	1.69	1.19	0.92	0.36
Neighborhood Density x 6dB SNR^b	0.08	0.04	1.00	1.16	1.08	2.02	0.04	0.00	0.02	0.96	1.04	1.00	0.10	0.92
Neighborhood Density x 15dB SNR^b	0.04	0.04	0.96	1.12	1.04	0.94	0.35	0.00	0.02	0.96	1.04	1.00	-0.01	0.99
Neighborhood Densityt x All Tests Slope	0.01	0.01	0.99	1.02	1.01	0.91	0.36	0.01	0.00	1.00	1.01	1.01	1.31	0.19
Neighborhood Density x Gap^a	0.02	0.04	0.94	1.10	1.02	0.46	0.65	-0.01	0.02	0.95	1.03	0.99	-0.67	0.50
						z	*p*						*z*	*p*
Participant intercept	0.85	0.19	1.60	3.38	2.33	4.47	<.0001	0.37	0.07	1.26	1.66	1.45	5.25	<.0001
Item intercept	0.47	0.19	1.10	2.32	1.60	2.48	0.02	0.24	0.10	1.06	1.53	1.27	2.54	0.02

Note. ^{a}Reference: no Gap; ^{b}Reference: 0dB SNR; *SE*: standard error; LCL: lower value of 95% confidence limits for the *OR*; UCL: upper value of 95% confidence limits for the *OR*; *OR*: odds ratio suggesting significant between-participant and between-item differences. Specifically, the probability of a correct response varied among participants, $z = 4.47$, $p < .0001$, $OR = 2.33$ (95% confidence limits [CL] = 1.60-3.38), and among items, $z = 2.48$, $p < .05$, $OR = 1.60$ (95% CL = 1.10-2.32). In the referent identification task, the random effects of participants and item were also significant, suggesting significant between-participant and between-item differences. Specifically, the response probability varied among participants, $z = 5.25$, $p < .0001$, $OR = 1.45$ (95% CL = 1.26-1.66) and among items, $z = 2.54$, $p < .05$, $OR = 1.27$ (95% CL = 1.06-1.53). Thus, in both naming and referent identification tasks, participant and item differences were significantly large with the magnitude of participant and item differences being larger in the naming task than the referent identification task.

A significant main effect of the expressive vocabulary test (EVT-2) score was found in the naming task, $t(62.79) = 2.74$, $p < .01$, $OR = 1.03$ (95% CL = 1.01-1.06) and in the referent identification task, $t(71.53) = 3.13$, $p < .01$, $OR = 1.02$ (95% CL = 1.01-1.04). Specifically, the probability of a correct response was increased by 3% ($OR = 1.03$) per each one point increase from the mean raw scores of the EVT-2 in the naming task and by 2% ($OR = 1.02$) in the referent identification task. These results indicate that children with more knowledge on expressive vocabulary are more likely to respond correctly than children with less knowledge on expressive vocabulary in the naming and referent identification tasks.

Noise Effect

The effect of noise was only significant at +6dB SNR with a reference of 0dB SNR in the naming task, $t(62.16) = 2.13$, $p < .05$, $OR = 1.87$ (95% CL = 1.05-3.32). Specifically, the probability of a correct response was 87% ($OR = 1.87$) higher when the noise level was +6dB realistic SNR compared to 0dB unfavorable SNR in the naming task. A non-significant effect of noise was found at +15dB recommended SNR with a reference of 0dB unfavorable SNR in the naming task, *t*(65.05) = 1.52, *p* = .13, *OR* = 1.56 (95% CL = 0.88-2.77). Turning to the referent identification task, a significant effect of noise was not found at either +6dB realistic SNR, *t*(71.17) = 1.22, *p* = .23, *OR* = 1.25 (95% CL = 0.87-1.79) or +15dB recommended SNR, *t*(71.70) = 0.90, *p* = .37, *OR* = 1.18 (95% CL = 0.83-1.68), with a reference of 0dB unfavorable SNR. Figure 3 illustrates the effect of noise on word learning in both tasks. Overall, word learning was better in the referent identification task than the picture naming task across all SNRs. Visual inspection showed that, in both tasks, word learning was the best at +6dB realistic SNR, followed by +15dB recommended SNR, and followed by 0dB unfavorable SNR. Thus, across tasks, the pattern was similar, although it only achieved significance in the naming task for +6dB realistic SNR vs. 0dB unfavorable SNR.

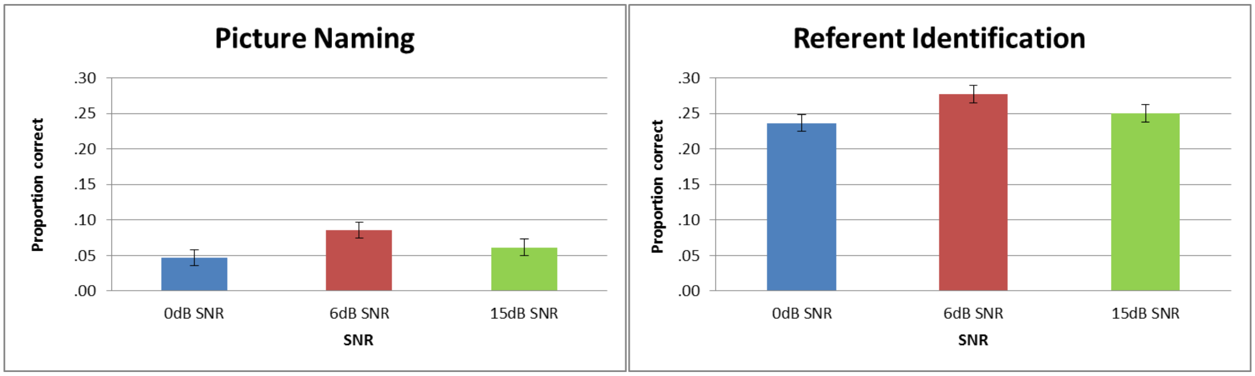


Figure 3. The effect of noise. The mean proportion of a correct response at each SNR in the picture naming task on the left panel and in the referent identification task on the right panel.

Interaction of Density and Noise

In the naming task, the main effect of density was not significant, *t*(32.23) = -1.23, *p* = .23, *OR* = 0.91 (95% CL = 0.79-1.06); however, the significant interaction of density and noise was found only at +6dB realistic SNR with a reference of 0dB unfavorable SNR, *t*(9648) = 2.02, *p* < .05, *OR* = 1.08 (95% CL = 1.00-1.16). Figure 4 represents the interaction between density and noise in the naming task and the referent identification task. In the naming task, at the mean density level, the probability of a correct response was 87% (*OR*= 1.87, 95% CL = 1.05-3.33) higher at +6dB realistic SNR compared to 0dB unfavorable SNR. This difference was increased by approximately 2.0%[1] per one-unit increase from the mean density level. These results suggest that density amplifies the effect of noise. That is, children are more likely to respond correctly at +6dB realistic SNR compared to 0dB unfavorable SNR and this difference becomes greater when density increases in the naming task.

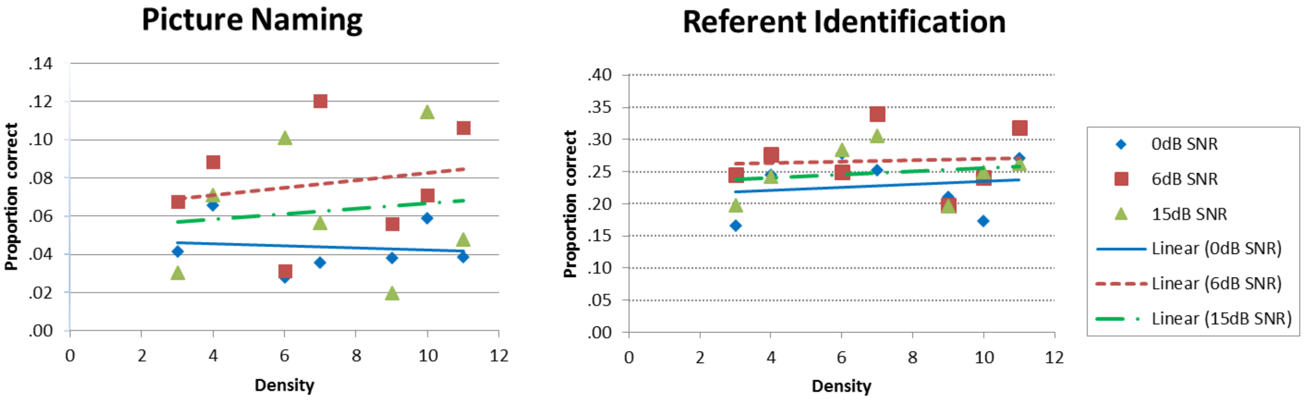


Figure 4. The interaction between density and noise. The mean proportion of a correct response is presented for each SNR over density in the picture naming task on the left panel and in the referent identification task on the right panel. The value points represent the real mean proportion of a correct response for each SNR over each density.

Follow-up analyses were conducted to disentangle the interaction between density and noise. In terms of the effect of density that varies by noise, a follow-up analysis showed no significant effect of density at each SNR, *t*(22.81) = - 0.58, *p* = .57, *d* = - .24 at 0dB unfavorable SNR; *t*(19.64) = - 0.17, *p* = .87 *d* = - .08 at +6dB realistic SNR; *t*(21.19) = - 0.55, *p* = .59, *d* = -

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[1] 10% (*OR* for density= 0.91) - 8.0% (*OR* for the interaction between density and +6dB SNR= 1.08)

.24 at +15dB recommended SNR. These results suggest that the current study does not support the prediction that noise amplifies the density effect. Visual inspection of Figure 4 suggests that in the naming task, no difference between high and low density was found at each SNR; however, a trend of the high density advantage was found at +6dB and +15dB SNRs but not at 0dB SNR. Thus, at 0dB unfavorable SNR, learning is too challenging, resulting in no difference by density; however, as SNR improves, the high density advantage starts to emerge but never reaches significance. In terms of the effect of noise that varies by density, follow-up analysis showed a significant difference between 0dB unfavorable SNR and +6dB realistic SNR only for high density, $t(83.13) = 2.23$, $p < .05$, $d = .49$, whereas no significant difference was found between any other SNR pairs. These results suggest that density amplifies the effect of noise. Visual inspection of Figure 4 shows that in the naming task, the noise difference is present at low density but larger at high density.

In the referent identification task, the main effect of density was not found, $t(20.18) = -0.15$, $p = .88$, $OR = 0.99$ (95% CL = 0.91-1.09). Also, the interaction between density and noise was not found at +6dB realistic SNR with a reference of 0dB unfavorable SNR, $t(9644) = 0.10$, $p = .92$, $OR = 1.00$ (95% CL = 0.96-1.04), or at +15dB recommended SNR with a reference of 0dB unfavorable SNR, $t(9644) = -0.01$, $p = .99$, $OR = 1.00$ (95% CL = 0.96-1.04) in the referent identification. These results indicate that density does not influence children’s performance on the referent identification task when noise is present.

Time Effect

Figure 5 illustrates the effect of time on the proportion of correct responses in the naming and the referent identification tasks. In the picture naming task, the main effect of time

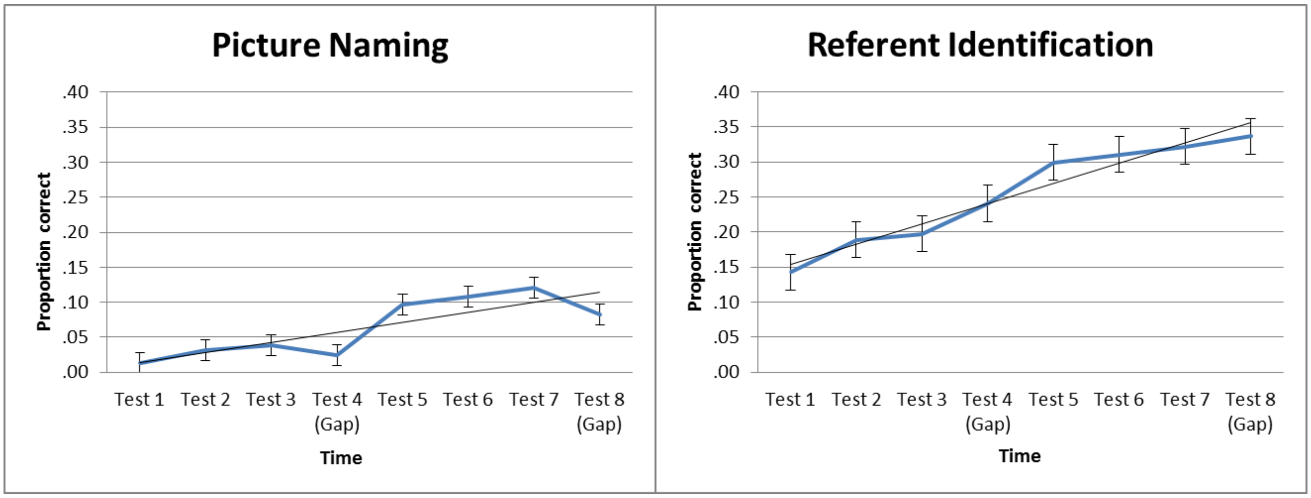

Figure 5. The main effect of time. The mean proportion of a correct response is presented over time in the picture naming task on the left panel and in the referent identification task on the right panel.

represented by All Tests Slope and Gap was significant for All Tests Slope, *t*(9648) = 14.96, *p* < .0001, *OR* = 1.43 (95% CL = 1.37-1.50), and for Gap, *t*(9648) = -8.29, *p* < .0001, *OR* = 0.37 (95% CL = 0.30-0.47). In terms of the time parameters, the parameter All Tests Slope showed a linear growth of learning in the naming task. Specifically, the probability of a correct response was increased by 43% (*OR* = 1.43, 95% CL = 1.37-1.50) in the naming task when each subsequent test was compared to the immediately preceding test. The parameter Gap showed forgetting. Specifically, the probability of a correct response was reduced by 37% (*OR* = 0.37, 95% CL = 0.30-0.47) for the test point following the no training gaps compared to the test point preceding the no training gaps. These results indicate that in the naming task, children are more likely to learn words over time but forget newly learned words when training is discontinued.

In the referent identification task, the main effect of All Tests Slope was significant, *t*(9644) = 14.91, *p* < .0001, *OR* = 1.20 (95% CL = 1.17-1.23), indicating a linear growth of learning. In contrast, the main effect of Gap was not significant in the referent identification task, *t*(9644) = -1.45, *p* = .15, *OR* = 0.92 (95% CL = 0.81-1.03). These results indicate that in the referent identification task, children are more likely to learn words over time and continue to improve even when training is withdrawn, indicating memory consolidation.

Interaction of Density and Time

In terms of the interaction of density and time, in the naming task, there were no significant effects of the interaction between density and All Tests Slope, *t*(9648) = .91, *p* = .36, *OR* = 1.01 (95% CL = 0.99-1.02), or the interaction of density and Gap, *t*(9648) = .46, *p* = .65, *OR* = 1.02 (95% CL = 0.94-1.10). In the referent identification task, there were no significant effects of the interaction between density and All Tests Slope, *t*(9644) = 1.31, *p* = .19, *OR* = 1.01 (95% CL = 1.00-1.01) or the interaction between density and Gap, *t*(9644) = -.67, *p* = .50, *OR* = 0.99 (95% CL = 0.95-1.03). These results indicate that regardless of density, children learn words in a linear manner with input in both tasks. Without input, children forget the newly learned words in the naming task while they remember the newly learned words in the referent identification task.

Discussion

This study explored how noise impacted the ability to learn novel words in 4- and 5-year-old children in preschool in the naming and referent identification tasks with a primary interest in the relationship between noise and neighborhood density. The current study found that a significant noise effect and a significant interaction between noise and density were found only in the naming task. In terms of noise effect, results showed better word learning at the realistic +6dB SNR listening condition compared to the unfavorable 0dB SNR listening condition. However, there was no significant effect of density and this non-significance persisted over time, which is inconsistent with past studies of the density effect on word learning in a quiet condition. The results imply that noise may dampen the density effect. In terms of the relationship between noise and density, results indicate that high density words are more sensitive to the effect of noise, and that any level of noise interferes with children's ability to use lexical representations in word learning. In addition, regardless of task, results showed a significant increase in word learning over time even in the presence of noise. Each research question will be addressed in turn.

(1) Does noise negatively influence word learning in preschool children?

As hypothesized from Riley (2010), the naming task was more sensitive to the effect of noise than the referent identification task. However, the pattern of results in the specific noise conditions in the naming task was not as expected. In the naming task, children learned words the best at the realistic +6dB SNR, the worst at the unfavorable 0dB SNR, and somewhere in between at the recommended +15dB SNR. These results are striking because the recommended SNR was predicted to be the best listening condition for word learning in this study. These results indicate that any amount of noise may be detrimental to word learning but the effect is not linear. In Riley's (2010) study, the effect of noise on word learning was found by comparing word learning in a quiet condition to the learning in +8dB SNR. In the current study, however, without a quiet condition, comparison was made among three noisy listening conditions. Thus, it is not clear how much noise is detrimental to word learning compared to a quiet condition. Accordingly, the comparison of a quiet listening condition to each of the three listening conditions would shed light on the non-linear effect of noise.

(2) What is the relationship between density and noise in word learning by preschool children?

It was predicted that noise would amplify the effect of neighborhood density in the unfavorable 0dB SNR listening condition. Due to the lack of a significant density effect across the three SNR conditions in both tasks, results do not support the prediction. This study found a significant interaction between density and noise in the naming task. Follow-up analyses revealed no density effect across SNRs but a significant noise effect for high density in the naming task.

The result of no density effect across SNRs is counter to past word learning studies that found the density effect in a quiet listening condition, indicating that noise detrimentally affects children's ability to use lexical representations of novel words. Specifically, in the triggering process, children might have difficulties in recognizing low vs. high density words in any level of noise, resulting in inefficient triggering of word learning. In the configuration process, high density words may facilitate word learning by being held longer and more accurately in working memory, due to receiving more return activation from the similar-sounding known words in long-term memory than low density words. Thus, without any support from high density words stored in long-term memory, children might not hold phonological forms of novel words within working memory in noise as much as they do in a quiet condition. This results in delayed construction of new lexical representations and/or delayed update of existing lexical representations, leading to construction of fragile lexical representations. In the engagement process, children might have difficulties in making connections in noise between new lexical representations and existing lexical representations to strengthen the lexicon.

The interaction between noise and neighborhood density may be explained by the idea of the neighborhood facilitation and inhibition. On one hand, neighbors may support the involvement of working memory in the configuration process of word learning and help develop robust representations in the engagement process of word learning, leading to the high density advantage. This is the neighborhood facilitation. On the other hand, neighbors may compete during word recognition in which low density words have fewer competitors than high density words. Thus, low density words are easier to be recognized as a target than high density words, leading to the low density advantage. This is the neighborhood inhibition. When noise is added, the neighborhood inhibition may be intensified, which limits the neighborhood facilitation, obscuring the high density advantage. In contrast, as the listening condition improves, the neighborhood facilitation may be highlighted and the high density advantage emerges. This idea is supported by a spoken word recognition study conducted by Taler et al. (2010) in which the low density advantage was greater in the challenging listening condition (-3dB SNR) than in the favorable listening condition (+10dB SNR). This result implies that noise obscures the high density advantage that occurs during configuration and engagement.

(3) Does the effect of neighborhood density change over time during word learning by preschool children?

It was predicted that children would learn more low density words during the first cycle of the training whereas they would retain more high density words after no training gap, which would replicate the findings of Storkel and Lee (2011). In addition, since this study has a longer time span than Storkel and Lee (2011), having three more cycles of training-testing and a second no training gap, it is interesting to examine how the density effect was changed in this extended time point. However, no main effect of density was observed, limiting the ability to address this research question. In addition, no interaction of time and density was found in either task. The results indicate that noise may hinder children’s ability to use lexical representations in the whole processes of word learning (i.e., triggering, configuration, and engagement), as mentioned above in the interaction between density and noise.

Results showed interesting differences in performance over time across tasks. A strong effect of time was found in the naming and referent identification tasks. That is, children's word learning improved as training progressed in both tasks with better learning in the referent identification than the naming task. In contrast, results showed different patterns of a time effect on two no training gap points in the tasks. In the naming task, the performance significantly declined at the two gap points, which suggests substantial forgetting during the no training gap. However, in the referent identification task, the improvement across the gap was similar to the one during training, indicating memory consolidation during the no training gap. These results imply that recall memory may be more vulnerable when training is withdrawn than recognition memory (Storkel, et al., 2014). However, it is not clear whether the use of different tasks accounts for forgetting in the naming task and memory consolidation in the referent identification task because in past studies, memory consolidation and forgetting have been observed in the both tasks. Therefore, future research is needed to reveal what causes forgetting or memory consolidation in word learning.

(4) Does noise influence children's performance on production and comprehension tasks of word learning?

It was predicted that noise would influence word learning when measured by a production task. When measured by a comprehension task, it was predicted that either (1) noise would not have an influence on word learning, as found in Riley's (2010) study on recognition; or (2) noise would have an influence on word learning, in accordance with existing studies on recognition (Elliot, 1979; Finitzo-Hieber & Tillman, 1978; Nittrouer & Boothroyd, 1990; Stelmachowicz, Hoover, Lewis, Kortekaas, & Pittman, 2000). Consistent with the first prediction, results revealed that the effect of noise was found in the naming task whereas it was not found in the referent identification task. These results are consistent with the findings in

Riley (2010) who investigated word learning either in a quiet condition or a +8dB SNR condition. Riley (2010) found that children named more words in a quiet condition than +8dB SNR, indicating that noise interfered with word learning as measured by the naming task; however, children's recognition performance did not show any differences between the two conditions as measured by the recognition task.

The difference across tasks may be attributed to the nature of the tasks. The picture naming task, an open-set task, taps recall memory that requires the child to search words saved in long-term memory to find the target word that corresponds to the picture presented on the computer screen, and then retrieve and plan to produce the word. Thus, in the naming task, only a retrieved word that has correct information saved in memory can be treated as a target item. In contrast, the referent identification task, a closed-set task, taps recognition memory that requires the child to compare the auditorily presented word to the limited number of words saved in long-term memory that correspond to the pictures presented on the computer screen, and to decide which picture among the pictures presented corresponds to the heard word. In the referent identification, even vague or partial information of a word saved in long-term memory can be sufficient to choose a correct picture. Thus, the picture naming task is more difficult in nature than the referent identification task. The differences across the naming and referent identification tasks used in this study are consistent with the effect of noise that was found in two text-reading tasks: recall question and recognition question (Hygge, Boman, & Enmarker, 2003). Hygge, Boman, and Enmarker (2003) found that noise adversely influenced young adults' performance on the recall question task but not on the recognition question (multiple-choice question) task. Taken together, a challenging word learning task, such as the naming task that requires more detailed lexical representation, may be more sensitive to noise than the referent identification task.

On the basis of the absence of a noise effect in the referent identification task in the current study, it might be hypothesized that noise was present but the level of noise was not excessive enough or the type of noise was not interfering enough to influence children's performance on recognition memory for newly learned words. Regarding the level of noise, even a less favorable noise condition may influence children's performance on word recognition. For example, Nittrouer and Boothryoyd (1990) found a significant effect of noise on word recognition when they used white noise to generate two levels of SNRs (i.e., 0 and -3 dB SNRs). That is, a significant effect of noise was found when they used an even less favorable level of noise (i.e., -3 dB SNR) than the least favorable level of noise (i.e., 0 dB SNR) used in the current study. Based on the typically found classroom noise levels of -7dB to +6dB (Blair, 1977; Crandell, 1993; Finitzo-Hieber, 1988; Markides, 1986; Picard & Bradley, 2001), classroom listening conditions below 0dB SNR may be encountered by young children making it worthwhile to investigate recognition memory under even worse listening conditions.

In terms of energetic vs. informational masking, this study used broadband white noise that is a steady-state unvarying noise over a wide range of frequencies. This type of background noise makes inaudible the portions of speech signal that share spectral-temporal information with the noise, producing energetic masking (Brungart, 2001). Energetic masking limits children's ability to use lexical knowledge as seen in the current study and increases children's reliance on acoustic cues (Mattys, Brooks, & Cooke, 2009). However, this type of noise has a different quality from the target words, making it easier to segregate the noise from speech sounds (Wightman & Kistler, 2005). In contrast, speech-shaped noise with an uncertainty and signal-like quality is hard to be segregated from the speech signal, producing informational masking (Brungart, 2001). Informational masking limits children’s reliance on acoustic cues and increases children’s reliance on lexical knowledge (Mattys, et al., 2009). Studies have found that children have an increased level of difficulty segregating target words in the presence of a speech distractor, compared to adults (Hall, Grose, Buss, & Dev, 2002). Also, children aged 4-5 years demonstrated greater information masking than adults (Wightman & Kistler, 2005). Although the HVAC systems are known as a major noise source in typical classrooms, multi-talker background noise is also present in classrooms and may have a detrimental effect on recognition memory for novel words. Thus, future studies with different types of noise may yield different results.

Limitations

The current study tried to reflect a classroom listening environment using the most influential noise source in classrooms, broadband white noise, but actual classroom listening conditions include much more complex characteristics such as different types of noise and high levels of reverberation, which differ from the experimental listening conditions. Children in classrooms are exposed to complex speech noise (e.g., multi-talker babble) from teachers and peers as well as broadband white noise from the HVAC systems. Complex speech noise may more detrimentally influence word learning than broadband white noise because the speech signal and noise signal cannot be easily disentangled in complex speech noise (Wightman & Kistler, 2005). Moreover, complex speech noise is known to more adversely influence children’s higher-level processing of acoustic signals than broadband white noise (Werner & Leibold, 2011; Wróblewski, Lewis, Valente, & Stelmachowicz, 2012). In addition to the types of noise in classrooms, reverberation is another source of noise in the classroom environment (ASHA, 2005). In classrooms, reverberation arises from the sounds that reflect off of hard surfaces such as desks, tables, ceilings, and floors, and then persist after the sound source stops. Excessive reverberation masks speech sounds that can be difficult to understand (e.g., Flexer, 2004). Thus, if a study on the effect of noise in the classroom uses both multi-talker babble and reverberation as its noise sources, then the study can reflect more a realistic listening environment in a typical classroom than a study using either one of these noise sources.

Conclusions

The central motivation for this study was that past studies on children's word learning have not successfully reflected the real word listening conditions where children are learning. Indeed, the results of the current study reveal that word learning declines as listening conditions worsen, supporting the idea that studies of word learning need to take listening conditions into account. Moreover, in a challenging task, noise interferes with children's ability to use a lexical representation, impacting the whole processes of word learning (i.e., triggering, configuration, and engagement). Future work will include a quiet listening condition to serve as a comparison condition for the three SNR conditions in the current study. This will quantify the effect of noise on children's word learning and clarify the non-linear effect of noise found in this study. Future studies will continue to examine the effects of mental representations (i.e., lexical, phonological and semantic representations) on word learning by children and adults in the presence of noise. These studies will contribute to the development of ecologically valid models of word learning and to the identification of what strategies will be used in the real world listening conditions. Moreover, these studies on the noise effects with typically developing children and adults will motivate investigations on the effects of mental representations on word learning in noise with children and adults who are highly susceptible to noise (e.g., people with hearing loss, second language learners, and children with auditory learning problems).

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Appendix A

Consonant Confusion

Density	Nonword	Initial Consonant	Confusion (%)	Final Consonant	Confusion (%)
Sparse	**gɛp**	**g**	**55**	**p**	**53**
	wæ b	**w**	**48**	**b**	**43**
	fag	**f**	**45**	**g**	**52**
	mib	**m**	**69**	**b**	**43**
	haf	*h*	*48*	*f*	*61*
	j ɪg	*j*	*71*	*g*	*52*
	maɪb	*m*	*69*	*b*	*43*
	fup	*f*	*45*	*p*	*53*
Dense	**boʊg**	**b**	**32**	**g**	**52**
	fip	**f**	**45**	**p**	**53**
	mum	**m**	**69**	**m**	**57**
	naɪk	**n**	**57**	**k**	**47**
	pe ɪg	*p*	*55*	*g*	*52*
	pa ɪf	*p*	*55*	*f*	*61*
	wap	*w*	*48*	*p*	*53*
	j ʌt	*j*	*71*	*t*	*54*

Note. The nonwords in bold were presented in Story 1. The nonwords in italic were presented in Story 2. For Story 1 and Story 2, no significant differences in the consonant confusions were found between sparse and dense neighborhoods for the initial consonants, *t*(6) = .37, *p* = .73, *d* = .26 for Story 1; *t*(6) = .12, *p* = .91, *d* = .08 for Story 2, and the final consonants, *t*(6) = -1.31, *p* = .24, *d* = - .93 for Story 1; *t*(6) = - .65, *p* = .54, *d* = - .46 for Story 2.

Appendix B

Sample Story Episode in Story 1

Episode 2	Scene	Narrative
Scene 1	Girl sitting on a swing. Boy pushing her hard.	Big Brother and Little Sister were swinging. Big Brother said "I can go higher than you!" Big Brother went very high. Little Sister said "I can go higher than that." Big Brother pushed her very high.
Scene 2	Boy blowing on orange trumpet with bell pointing down. Girl blowing on yellow hand-held tuba.	Little Sister said, "I can play more music than you." Big Brother said, "No, you can't." "I can play lots of songs on my /**mum**/." Listen to me play my /**mum**/." He played his /**mum**/. "I played lots of music on my /**mum**/. My /**mum**/ is the best." Little Sister said "Oh, yeah? I can play more songs on my /**fag**/. Listen to me play my /**fag**/." She played her /**fag**/. "I played lots of music on my /**fag**/. My /**fag**/ is the best."
Scene 3	Boy dancing with red candy having 1 chute in thought cloud. Girl cancing with blue candy having 2 chutes in thought cloud.	Big Brother said "I can eat more candy than you." Big Brother's favorite candy was from the /**gɛp**/. He ran to the /**gɛp**/. He got candy from the /**gɛp**/. He stuffed all the candy from the /**gɛp**/ in his mouth. The candy from the /**gɛp**/ was really good. "Can you eat that much?" Little Sister's favorite candy was from the /**boʊg**/. She ran to the /**boʊg**/. She got candy from the /**boʊg**/. She stuffed all the candy from the /**boʊg**/ in her mouth. The candy from the /**boʊg**/ was really good.Then, they got more candy for later.
Scene 4	Boy walking gerbi with antenna on a leash. Girl carrying purple mouse-bat.	Little Sister said "I can make our pets do more trics than you." Big Brother said, "Uh-uh," Big Brother made /**mib**/ do tricks. He made /**mib**/ roll-over. He made /**mib**/ jump up and down. He gave /**mib**/ a treat. Big Brother was proud of /**mib**/ a treat. Next, it was Little Sister's turn. Little Sister made /**naɪk**/ do tricks. She made /**naɪk**/ roll-over. She made /**naɪk**/ jump up and down. Then, she gave /**naɪk**/ a treat, too. Little Sister was proud of /**naɪk**/

Scene 5	Boy standing and holding punch toy. Girl sitting and holding cork gun.	Big Brother said "I can hit more rocks with my toy than you." Big Brother set up the rocks. Big Brother got out his /**fip**/. He pointed the /**fip**/ at the rocks. He hit a rock with his /**fip**/. He hit lots of rocks with his /**fip**/. Then, he put the /**fip**/ back to his backpack. Little Sister put the rocks back. Little Sister got out her /**wæb**/. She pointed the /**wæb**/ at the rocks. She hit a rock with her /**wæb**/. She hit lots of rocks with her /**wæb**/. Then, she put the /**wæb**/ back to her backpack.
Scene 6	Boy and girl walking down hand in hand.	Big Brothe looked at his watch. "It's time to go home." They walked home hand in hand. What will they play when they get home?

Note. Four alternative versions for each story were used to countbalance nonword-novel object referent pairs across participants.

Appendix C

Seven Models: Odds Ratios and 95% Confidence Limits in the Naming Task

Parameter		Model 1 Individual Difference	Model 2 Vocabulary Knowledge	Model 3 Neighborhood Density	Model 4 Time	Model 5 Noise	Model 6 Density X Noise	Model 7 Density X Time
Age			1.0489 (0.9952, 1.1057)	1.0482 (0.9950, 1.1043)	1.0491 (0.9937, 1.1075)	1.0440 (0.9894, 1.1016)	1.0440 (0.9894, 1.1017)	1.0440 (0.9894, 1.1017)
EVT - Raw Score			1.0340* (1.0048, 1.0641)	1.0317* (1.0080, 1.0559)	1.0325* (1.0079, 1.0578)	1.0340** (1.0095, 1.0591)	1.0340** (1.0095, 1.0592)	1.0341** (1.0095, 1.0592)
PPVT - Raw Score			0.9974 (0.9787, 1.0164)					
Neighborhood Density				0.9892 (0.8837, 1.1074)	0.9888 (0.8781, 1.1134)	0.9888 (0.8780, 1.1135)	0.9482 (0.8340, 1.0780)	0.9127 (0.7889, 1.0560)
All Tests Slope					1.4320*** (1.3661, 1.5011)	1.4326*** (1.3666, 1.5018)	1.4329*** (1.3669, 1.5021)	1.4343*** (1.3681, 1.5038)
Gap					0.3756*** (0.2979, 0.4735)	0.3753*** (0.2977, 0.4732)	0.3750*** (0.2974, 0.4729)	0.3746*** (0.2970, 0.4725)
SNR	6 (ref.0dB)					1.8554* (1.0446, 3.2956)	1.8696* (1.0517, 3.3233)	1.8705* (1.0521, 3.3256)
	15 (ref.0dB)					1.5454 (0.8716, 2.7401)	1.5588 (0.8785, 2.7660)	1.5592 (0.8785, 2.7674)
Density X SNR	Density X 6dB						1.0777* (1.0013, 1.1600)	1.0789* (1.0023, 1.1613)
	Density X 15dB						1.0366 (0.9604, 1.1189)	1.0373 (0.9610, 1.1196)
Density X All Tests Slope								1.0074 (0.9916, 1.0234)
Density X Gap								1.0184 (0.9416, 1.1016)
N		9660	9660	9660	9660	9660	9660	9660
Participant Estimate (*SE*)		1.0051*** (0.2102)	0.8199*** (0.1827)	0.8060*** (0.1785)	0.8810*** (0.1932)	0.8431*** (0.1899)	0.8447*** (0.1902)	0.8453*** (0.1903)
Item Estimate (*SE*)		0.3917* (0.1537)	0.3927* (0.1541)	0.4212* (0.1702)	0.4683* (0.1887)	0.4692* (0.189)	0.4703* (0.1895)	0.4709* (0.1897)

$^{*}p < .05$
$^{**}p < .01$
$^{***}p < .0001$

Appendix D

Seven Models: Odds Ratios and 95% Confidence Limits in the Referent Identification Task

Parameter		Model 1	Model 2	Model 3	Model 4	Model 5	Model 6	Model 7
		Individual Difference	Vocabulary Knowledge	Neighborhood Density	Time	Noise	Density X Noise	Density X Time
Age			1.0086 (0.9766, 1.0417)	1.0094 (0.9776, 1.0421)	1.0087 (0.9759, 1.0425)	1.0071 (0.9741, 1.0412)	1.0071 (0.9741, 1.0412)	1.0071 (0.9741, 1.0412)
EVT - Raw Score			1.0211* (1.0033, 1.0392)	1.0235** (1.0090, 1.0382)	1.0238** (1.0088, 1.0390)	1.0240** (1.0089, 1.0393)	1.0240** (1.0089, 1.0393)	1.0240** (1.0089, 1.0393)
PPVT - Raw Score			1.002687605 (0.9910, 1.0145)					
Neighborhood Density				1.0102 (0.9314, 1.0958)	1.0106 (0.9294, 1.0988)	1.0106 (0.9293, 1.0989)	1.0101 (0.9259, 1.1020)	0.9930 (0.9060, 1.0885)
All Tests Slope					1.1965*** (1.1686, 1.2250)	1.1966*** (1.1687, 1.2252)	1.1966*** (1.1687, 1.2252)	1.1965*** (1.1686, 1.2251)
Gap					0.9148 (0.8117, 1.0311)	0.9148 (0.8117, 1.0311)	0.9148 (0.8117, 1.0311)	0.9151 (0.8119, 1.0314)
SNR	6 (ref.0dB)					1.24820 (0.8727, 1.7853)	1.2481 (0.8726, 1.7851)	1.2482 (0.8727, 1.7853)
	15 (ref.0dB)					1.1806 (0.8296, 1.6800)	1.1806 (0.8296, 1.6800)	1.1806 (0.8294, 1.6803)
Density X SNR	Density X 6dB						1.0019 (0.9617, 1.0438)	1.0022 0.9620, 1.0440)
	Density X 15dB						0.9994 (0.9593, 1.0412)	0.9998 (0.9597, 1.0415)
Density X All Tests Slope								1.0054 (0.9973, 1.0134)
Density X Gap								0.9861 (0.9466, 1.0271)
N		9656	9656	9656	9656	9656	9656	9656
Participant Estimate		0.4059***	0.3470***	0.3428***	0.3683***	0.3710***	0.3710***	0.3711***
(*SE*)		(0.0740)	(0.0660)	(0.0648)	(0.0693)	(0.0707)	(0.0707)	(0.0707)
Item Estimate		0.2122*	0.2125*	0.2272*	0.2415*	0.2417*	0.2417*	0.2420*
(*SE*)		(0.0810)	(0.0811)	(0.0895)	(0.0950)	(0.0951)	(0.0951)	(0.0952)

*$p < .05$
**$p < .01$
*** $p < .0001$