

An Examination of Lexical Neighborhood Density in Young Children's Word Learning and
Phonological Awareness

by

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ABSTRACT

The lexical restructuring model aims to explain the developmental origins of the phoneme as a unit in implicit and explicit phonological processing tasks (Metsala & Walley, 1998). Very little research, however, has directly examined the claims of the model using experimental methods — best suited for testing causal claims. One way this study explored claims of this model was by attempting to manipulate the lexical neighborhood density for a subset of items and examining the effects on early elementary students' word learning and phonemic awareness. Additionally, the associations between task performance for items from different neighborhood densities and early literacy-related skills were examined. Twenty-nine students in kindergarten and 33 students in grades one and two completed a word learning training task that introduced 18 nonword-nonobject pairs. Six nonwords were from sparse neighborhoods, but had phonological neighbors introduced during the learning task (creating a sparse-to-dense condition) to experimentally facilitate lexical restructuring — or direct attention to the internal structure of these new items. Immediate word learning measures and pre- and post-test phonemic blending for the 18 nonwords were completed. Measures of word reading, phonological awareness, and nonword repetition were also completed. Overall, introducing neighbors for the six items did not facilitate word learning. However, the younger group did show greater gains in pre-to-post-test phoneme blending for items in the sparse-to-dense condition compared to items in the sparse and the dense conditions. Furthermore, repetition of multisyllabic nonwords composed of syllables with few lexical neighbors explained unique variance in word learning beyond grade and repetition of nonwords with many lexical neighbors. In the final analysis, phoneme blending for sparse nonwords explained unique variance in word reading beyond grade, general phonological awareness, and phoneme blending for dense nonwords. Overall, experimental support for a

central claim of the lexical restructuring model was found in the younger sample. This study also provides correlational evidence related to the idea that processing words from sparse lexical neighborhoods (i.e., areas of the mental lexicon to undergo segmental restructuring the latest in development) is a better index of the degree of segmentation in lexical representations, and thus of individual differences in word reading development.

Keywords: lexical restructuring, vocabulary growth, phonological processing, neighborhood density

Introduction

Learning to read is a key academic skill that is foundational to success in later school years. Children who begin as strong readers get off to a better start in school, read more frequently (Bus & Mol, 2011; Cunningham & Stanovich, 1997; Sénéchal & Lefevre, 2002), and may, in turn, acquire a greater breadth and depth of vocabulary and world knowledge (Cunningham & Stanovich, 1998). Phonological processing (i.e., the various cognitive abilities that are collectively performed on the sound system of spoken language; Metsala, 1997), has a pivotal role in the acquisition of early literacy skills (Liberman & Shankweiler, 1989; Wagner & Torgesen, 1987; 1997). Researchers now widely accept that phonemic awareness is one category of phonological processing that is instrumental in learning to read and is often a source of difficulty for students with reading disabilities (Bruck, 1992; Lundberg et al., 1988; Metsala, 1999). Research has also been directed toward studying other phonological processes related to language and reading development (for reviews, see Mody, 2003; Wagner & Torgesen, 1987).

One aim of research has been to explain the developmental origins of the phoneme as a unit that children become increasingly aware of. A key assumption underlying emergent theories of the development of the phoneme is that words are first represented more holistically, but become increasingly segmental (i.e., phonemic) - perhaps prompted by the vocabulary growth spurt starting at approximately 18-24 months of age (e.g., Fowler, 1991; Metsala & Walley, 1998; see Reznick & Goldfield, 1992). In order to discriminate among the increasing number of known words, more fine-grained or segmental representations of spoken words appear necessary, resulting in representations that are increasingly organized around the phoneme (e.g., Jusczyk, 1986; 1993). This development and later explicit processing is proposed to be a protracted process, occurring across an extended period into the earliest school years and the beginning of

formal reading instruction (Fowler, 1991; Metsala & Walley, 1998). The lexical restructuring model proposed by Metsala & Walley (1998) offers one account of developmental changes in the structure of spoken word representations that occur during childhood, as well as how these changes are related to implicit and explicit phonological processing (Metsala, 2011a). The goal of the current study is to examine several claims made by the lexical restructuring model as they relate to individual differences in skills linked to the notion of lexical restructuring or reorganization. In this study, young students' performance on word learning and phonological awareness tasks were examined as a function of grade and lexical characteristics. The proposed association of performance on these tasks with word reading is also examined. In this introduction, theories and research that support the examination of this topic are first introduced. I then review related research on the development of phonological awareness, word learning, and word reading.

Developmental Origins of the Phoneme as an Implicit and then Explicit Unit

Phonemic awareness is the ability to detect and manipulate the smallest individual sounds (phonemes) in spoken words and is an important skill in reading acquisition (Catts, 1993; Wagner & Torgesen, 1987). Early phonological awareness skills, such as the recognition of rhyming words and syllables within words (i.e., phonological sensitivity), may be acquired by children during the preschool years before formal reading instruction. Phonemic awareness emerges later in development, coinciding with beginning reading instruction (Brady, 2020; Lonigan et al., 1998). This ability to access and manipulate the sound structure of language at the level of the phoneme is critical to successful literacy development (Brady & Shankweiler, 1991; Bus & van IJzendoorn, 1999; National Reading Panel, 2000; see also Ehri et al., 2001). Phonemic awareness is one of the strongest predictors of word reading skills (Wagner &

Torgesen, 1987), deficits in phonemic awareness are frequently found in children who have difficulties in acquiring word reading skills, and instruction in phonemic awareness supports learning to read words (Hulme et al., 2012; Liberman et al., 1989; for a review, see Hulme & Snowling, 2013).

While the importance of phonemic awareness in early literacy acquisition is well studied, less is known about the developmental origins of the phoneme as a consciously accessible unit. One proposal is that as the size of the lexicon and lexical similarity relations among known words increase, the phoneme emerges first as an implicit unit used in spoken word recognition, and then later becomes available for more explicit cognitive activities (i.e., phonemic awareness and learning to read; Metsala, 1999; 2011a; Walley, 1993). That is, spoken word representations and the organization of the mental lexicon appear to undergo developmental changes during a period spanning the preschool years to the initial elementary school years. These representational changes are proposed to enable metacognitive phonemic awareness activities (for a review see, Metsala, 2011a; see also Storkel, 2002).

According to McDowell and Lonigan (2006), two primary theories have been put forth to explain this conscious access and awareness of the phonemic level of spoken words. Both accounts share the basic assumption that the earliest representations of words in lexical memory or the lexicon (i.e., the listener's 'mental dictionary') are different than they are for older listeners and develop with both age and language experience (see Elbro, 1996, and Metsala & Walley, 1998). One account is the phonological distinctness hypothesis, which posits that individual differences in the amount of phonetic detail (i.e. distinctness) stored in lexical representations for words in long-term memory are associated with individual differences in phonemic awareness, along with various other phonological processing skills (Elbro et al., 1996;

Elbro et al., 1998). Specifically, distinctness is indexed by the amount of precision in children's pronunciations of speech sounds in complex words and indicates how phonetically complete and accurate a given lexical representation is, as well as how accessible the sub-lexical phonological units that comprise it are (Elbro, 1996; Elbro, et al., 1994).

Elbro (1996, p. 454) hypothesized that "...differences in distinctness of phonological representations of lexical items is a cause of many of the diverse differences in phonological processing associated with success or failure in reading development." Elbro argued that children with more phonetically precise and complete (i.e., highly distinct) representations would possess stronger phonological processing skills than children whose representations lack precision and phonetic detail (i.e., less distinct) and that these differences would be reflected in phonological processing tasks, such as the precise pronunciation of complex multisyllabic words (i.e., speech-sound accuracy) and phonemic awareness (Elbro, 1996). Elbro and colleagues' research efforts have found support for the claims made by the phonological distinctness hypothesis. For example, Elbro et al., (1998) found that kindergarteners' accuracy in pronouncing familiar multisyllabic words (i.e., distinctness of lexical representations) predicted initial reading ability, as well as phonemic awareness and reading ability in grade two. Elbro & Pallesen (2002) found that training representations of spoken words to become more phonetically precise was associated with improvements in kindergarten children's phoneme awareness specific to trained words, but not untrained words. Overall, these findings lend support to the phonological distinctness hypothesis.

The second account of the emergence of the phoneme as a unit underlying lexical representation and organization is the lexical restructuring model (Metsala & Walley, 1998). Under this model, the phoneme is proposed to first emerge as an implicit unit in language

processing, and later as a unit for explicit processing. This theory is built upon the Word Recognition and Phonetic Structure Acquisition (WRAPSA) model of spoken word recognition development across infancy and toddlerhood (Jusczyk, 1986; 1993; 1995). Jusczyk's empirical studies have supported his model in which infants' and toddlers' initial representations of words are relatively holistic, rather than clearly defined sequences of phonemes like those in older listeners (e.g., Walley et al., 1986). A holistic level of representation is adequate for these younger listeners, given that they have relatively few words stored in lexical memory that need to be distinguished from one another during the processes involved in spoken word recognition. For example, it has been proposed that phonological features, such as place of articulation and salient syllables, may form the basis of early word recognition (e.g., Jusczyk, 1986; Walley, 2006).

In building on this work in infancy and toddlerhood, the lexical restructuring model proposed that key changes in spoken word representations extend into early childhood and the beginning school years when children are learning to read. Specifically, the theory provides an account of how children's representations of spoken words become increasingly segmental (i.e., phonemic) with increasing vocabulary knowledge (Metsala & Walley, 1998; see also Fowler, 1991). Research findings supporting this notion have come from examinations of young children's performance on spoken word recognition tasks, which have found their representations of spoken words to be less well-developed than those in older children and adults. First, studies using gating paradigms have shown that 5–7-year-old children require more acoustic-phonetic input to recognize words than adults (e.g., Elliott et. al, 1987; Walley, 1988). Second, structural analyses of young children's lexicons have been shown to consist mainly of phonetically dissimilar words up to 7 years of age – recognition of which may be achieved through holistic

rather than segmental processes (e.g., Charles-Luce & Luce, 1990; Logan, 1992). Third, it was demonstrated that 8-year-old children could successfully classify spoken nonwords together based on a single common phoneme. In comparison, 5-year-old children required more similarity across the whole nonword pattern to do so (Walley et al., 1986; see also Treiman & Breaux, 1982; for a review, see Walley, 1993). The lexical restructuring model extends the timeframe of developmental changes in spoken word representations and links these to the emergence of phonemic awareness. One proposal is that as the number of words a child knows continues to increase, and more and more words overlap in their phonological structure, lexical representations based on more holistic units of sound (such as place of articulation and salient syllables) are no longer adequate to distinguish them quickly and accurately.

Segmental restructuring is proposed to be a protracted process throughout early childhood and not an all-or-none phenomenon – that is, not all words become segmentally represented at the same point in time (Metsala & Walley, 1998; see also Storkel, 2002; Treiman & Barron, 1981). As the young listeners' lexicon becomes more crowded through learning new words, areas of the lexicon become increasingly dense with similar-sounding words (i.e., dense lexical neighborhoods). This increasing density necessitates more fine-grained information to be stored in lexical representations in order to efficiently distinguish between the growing number of phonological neighbors (Metsala & Walley, 1998; Walley et al., 2003). These more mature representations are based on sequences of phonemes, as per adult models of spoken word recognition (e.g., Charles-Luce & Luce, 1990).

A central claim of the lexical restructuring model is that this segmental restructuring, needed for the implicit task of recognizing spoken words, gives rise to phonemic awareness – the ability to consciously access and manipulate the phoneme (Metsala & Walley, 1998). Research

on spoken word recognition in adults has supported models in which stored spoken word representations are organized into phonological neighborhoods based on phonemes, and that lexical neighborhood density has effects on the process of spoken word recognition (e.g., Goldinger et al., 1989; Luce & Pisoni, 1998). In summary, the lexical restructuring model and similar developmental proposals (e.g., Storkel, 2002), claim that segmental representation is initially related to the need for finer distinctions between items in more crowded areas of the lexicon, rather than something that occurs across all lexical items simultaneously.

The lexical restructuring model holds three claims relevant to the current study, as they are summarized here. First, the overall size (i.e., breadth) of an individual's vocabulary should be directly related to performance on implicit tasks of spoken word recognition and explicit phonological awareness tasks. Second, lexical restructuring depends not only on overall vocabulary size, but also on characteristics of individual lexical items and the overall developing lexicon - specifically, experience and familiarity with individual words, as well as phonological neighborhood density (Metsala, 2011a; Metsala & Walley, 1998; Storkel, 2002; 2004). These first two claims can be conceptualized as proposing that segmental restructuring/processing is related to multifaceted vocabulary growth, including global factors (i.e., the size of the lexicon) and local factors (e.g., word frequency/familiarity and neighborhood density; Metsala, 1999). Third, for tasks reliant on lexical representations of words, individual differences in performance across such tasks should be associated with one another. Therefore, individual differences in performance on implicit tasks (such as spoken word recognition and nonword repetition) will be related to performance on explicit tasks (such as phonemic awareness). I next review research related to each of these three central claims of the model.

The Lexical Restructuring Model and Phonological Awareness Performance, Vocabulary Size, and Word Familiarity

Regarding the first claim of the lexical restructuring model, a growing body of research has established a link between vocabulary breadth and phonological awareness. Studies have generally found substantial correlations between these variables in young children. For example, 4-6-year-old children's receptive vocabulary and a composite of phonological awareness had a correlation coefficient of .66 (Metsala, 1999). Other studies have reported similar findings, with ranges between .30 and .80 (e.g., Chaney, 1992; Dickinson et. al., 2003; Garlock et. al., 2001; McDowell et. al., 2007; Scarborough, 1990; Sénéchal & LeFevre, 2002). Vocabulary breadth has also generally been found to contribute unique variance to concurrent and later measures of phonological awareness in young children (e.g., Carroll & Snowling, 2001; Cooper et. al., 2002; Lonigan et. al., 2000; McDowell et. al., 2007; Metsala, 1999; Sénéchal & LeFevre, 2002). A small number of experimental studies have also found causal support for this claim (e.g., Lonigan, 2007). A more detailed review of research that bears directly on this claim will be reviewed in a subsequent section of this paper. The second claim of the lexical restructuring model argues that the time-course of lexical restructuring depends on local factors, whose influence is constrained to particular lexical items or areas of the lexicon where certain items reside. Local factors have been defined in terms of the familiarity or experienced frequency of an individual word by a listener, as well as the phonological similarity relations amongst items stored in the lexicon (e.g., Charles-Luce & Luce, 1990; Metsala, 1999). The lexical restructuring model proposes that listeners gain more language experience with earlier acquired words and those experienced more frequently when recognizing spoken language. In support of this argument, children have been found to perform better on phonological awareness tasks with

words estimated to be acquired earlier (e.g., Goodrich & Lonigan, 2015; Metsala, 1999) and with words experienced more frequently (e.g., Hogan et. al, 2011; Roth et. al, 2006; Troia et. al, 1996).

Neighborhood Density

Changes in the phonological similarity relations between words in the listener’s lexicon represent another type of vocabulary growth. Phonological similarity has been measured in terms of lexical neighborhood density, and is defined as the number of words in the lexicon that differ from a target word by a one-phoneme substitution, deletion, or addition in any position (Luce, 1986; Luce & Pisoni, 1998). Words that have many phonologically similar neighbors are said to reside in “dense” neighborhoods and those with few similar-sound neighbors reside in “sparse” neighborhoods. Research has demonstrated that the organization of words in the lexicons of adults is based on this metric of phonemic similarity (e.g., Luce & Pisoni, 1998; Goldinger et al., 1989). Young 4-5-year-olds’ lexicons appear to be organized based on phonemic similarity for words in dense neighborhoods, but by more gross similarity relations (i.e., manner class) in the rhyme position for words in sparse neighborhoods (Storkel, 2002).

Neighborhood density for specific words changes across development through vocabulary growth (Coady & Aslin, 2003; Charles-Luce & Luce, 1990), although even adult listeners continue to have words that remain in relatively sparse neighborhoods (Luce, 1986). Neighborhood density is measured by reference to online databases representing lexical knowledge in children and adults. A measure of neighborhood density for words in the adult lexicon is given by Aljasser and Vitevitch (2022). Adult lexicons contain more words overall than children’s lexicons, and thus neighborhood density is more equivalent across words (e.g., Charles-Luce & Luce, 1990). Researchers have also compiled online lexicons representing the

word knowledge of younger children. Storkel and Hoover (2010) created a neighborhood density calculator of approximately 5000 words based on the child corpus, accounting for the fact that child density tends to be lower than adult density for the same word (Coady & Aslin, 2003). For example, the word “cot” would be said to reside in a dense neighborhood, as it has an estimated adult density of 35 word neighbors and an estimated child density of 21 word neighbors. In contrast, the word “fuzz” would be said to reside in a sparse neighborhood, as it has an estimated adult density of 10 word neighbors and an estimated child density of 6 word neighbors (Aljasser & Vitevitch, 2022; Storkel & Hoover, 2010).

Words from dense neighborhoods are more likely to undergo restructuring earlier than words from sparse neighborhoods due to a higher need for differentiation. It is therefore proposed that early phonological awareness should be better for words residing in dense neighborhoods than for words residing in sparse neighborhoods (Metsala & Walley, 1998; Fowler, 1991). While beyond the scope of this paper, it has been proposed that learning new similar-sounding words may prompt the reorganization of existing words in the lexicon into phoneme-based similarity neighborhoods, as opposed to basic structural changes in the representation of words. Both possibilities (i.e., changes in basic word representations and/or changes in lexical organization based on the phoneme) are consistent with the same claims of the lexical restructuring model – that is, these two proposals lead to phonemic-level processing for both implicit and explicit tasks (Storkel, 2002; see also Metsala, 2011a; Walley, 2006).

Several studies have found evidence supporting the claim that words residing in dense neighborhoods would be associated with better performance on phonological awareness tasks. Metsala (1999) found that three-and-four-year-olds were better at phoneme blending for words from dense versus sparse neighborhoods. Goswami and DeCara (2000; 2003) found that words

from dense neighborhoods showed an advantage over words from sparse neighborhoods in five-year-old children's performance on a rhyme oddity task, as well as five-and-six-year-old children's performance on rhyme oddity and rime judgment tasks. Hogan et al. (2011) examined children's performance on a phoneme deletion task in grade two and again in grade four. They predicted that the effects of neighborhood density on phoneme deletion performance would be stronger in grade two than in grade four, reasoning that vocabulary growth may result in neighborhood density becoming more equivalent across words by the time the participants reached fourth grade. Phoneme deletion performance in both grades was better for words from dense versus sparse neighborhoods, with the effect of neighborhood density stronger in second grade than in fourth grade. Overall, these results support the position in the lexical restructuring model that the influence of lexical characteristics should be stronger earlier in development. On the one hand, younger children have smaller vocabularies, less experienced frequency with words, and more sparse areas of the mental lexicon than older children and adults (Metsala, 2011a; Metsala & Walley, 1998). On the other hand, both phonemic awareness instruction and learning to read require explicit manipulation at the phonemic level – thus, explicit processing eventually becomes a skill which is less tied to emergent factors such as neighborhood density (Metsala, 1999). Storkel (2004) found that as the number of words that children know increases, neighborhood density becomes more equivalent across words. Consistent with this finding, Metsala (1999) found that 4-year-olds' performance on onset-rime and phoneme blending tasks was sensitive to word frequency. In comparison, 5-year-olds' performance was sensitive to word frequency on the phoneme blending task, but not on the onset-rime blending task. The implication is that phonemic processing may initially be constrained by lexical characteristics of words before progressively becoming independent later in development through increasing

vocabulary knowledge, as well as direct instruction and practice in skills that require accessing and manipulating phonemes, such as reading, spelling, and phonemic awareness.

The third claim proposed by the lexical restructuring model is that individual differences in spoken word recognition (and other implicit phonological processing tasks, such as nonword repetition) are directly related to performance on phonological awareness tasks, and in turn, word reading. Spoken word recognition can be defined as matching speech input to the stored representations of words in one's lexical memory (Walley, 1993). Recognizing spoken words is a competitive process in which the spoken input activates a neighborhood of similar-sounding word representations that compete with one another for recognition (Luce & Pisoni, 1998). This third claim is based on the rationale that both implicit tasks and explicit tasks rely on the same representations of spoken words stored in the mental lexicon (Metsala, 2011a; Metsala & Walley, 1998).

Several studies have examined and found support for this association between implicit and explicit task performance (e.g., Garlock et al., 2001; McBride-Chang et al., 1997; Metsala et al., 2009). Metsala et al. (2009; see also Garlock et al., 2001) found that word naming in noise predicted phonological awareness one year later in children in grades 1 to 4. They also found that sparse word performance on a composite measure of spoken word recognition was indirectly related to word reading one year later through concurrent phonological awareness. These findings support the lexical restructuring model's claim that implicit phonological processing is directly related to performance on phonological awareness tasks and indirectly related to word reading. Research related to this third claim will be reviewed in subsequent sections of this paper.

In summary, both the phonological distinctness hypothesis and the lexical restructuring model provide separate (albeit closely related) accounts of the development of phonemic awareness. McDowell et al. (2006) suggest that the phonological deficit hypothesis emphasizes the predictive role of speech-sound accuracy skills (i.e., sublexical level), whereas the lexical restructuring model emphasizes the predictive role of aspects of vocabulary growth (i.e., lexical level) on tasks requiring sublexical processing. McDowell et al. (2006) found that preschool children's speech sound accuracy abilities (as measured by a nonword repetition task and a single-word naming task) and vocabulary breadth both predicted unique variance in phonological awareness, suggesting that these two theories may be complementary to one another in accounting for the development of implicit and explicit phonological processing. (McDowell et al., 2006; see also Elbro, 1996). The current study sought to empirically evaluate the aforementioned claims held by the lexical restructuring model, with a specific focus on examining the causal role that neighborhood density is proposed to play.

Phonological Awareness and Vocabulary Growth: A Causal Relationship?

While the lexical restructuring model makes explicit predictions regarding the causal role of vocabulary growth and lexical characteristics in the development of phonological awareness, evidence to date has largely been correlational (Lonigan, 2007; Metsala, 2011a). Some longitudinal studies, however, have examined this relationship. For example, Lonigan et al. (2000) found that a latent oral language variable (including vocabulary breadth) measured in preschool contributed unique variance to concurrent phonological awareness and growth in phonological awareness one year later in kindergarten. Burgess & Lonigan (1998) found a significant correlation between beginning oral language skills and phonological awareness in 97 4-year-old children, but their oral language skills were not a strong predictor of growth in

phonological sensitivity. However, the measures of oral language were grammatical closure and grammatical understanding, rather than vocabulary breadth. Cooper et. al. (2002) followed 52 children from kindergarten to grade two and found that oral language measured in kindergarten significantly predicted concurrent and subsequent phoneme awareness in first and second grade. Carroll & Snowling (2001) demonstrated similar findings in a longitudinal study of 38 younger children aged 3-4 years old, in which receptive vocabulary breadth predicted significant growth in phonological awareness over one year.

Lonigan et. al (2000), Cooper et. al (2002), and Carroll & Snowling (2001) each concluded that their findings support the argument that the development of vocabulary breadth influences growth in phonological awareness and that lexical representations become more segmental through vocabulary growth. Overall, these findings parallel those reported in similar studies (e.g., McDowell et. al., 2007; Metsala, 1999; Sénéchal & LeFevre, 2002). However, the unique contributions of vocabulary breadth could not be assessed in the studies by Lonigan et. al (2000) and Cooper et. al (2002) due to their use of a general oral language variable. Furthermore, none of these studies conducted analyses in which oral language/vocabulary breadth was included as a variable predicting phonological awareness, thereby limiting insight into the direction of this relationship.

Other longitudinal studies, however, have clarified the direction of the potential causal relationship between early vocabulary knowledge and later phonological awareness skills. Torppa and colleagues (2007) followed 186 children from birth to 6.5 years of age. They found that vocabulary breadth measured at 3.5 years predicted significant variance in a latent phonological awareness variable derived from measurements taken at 4.5, 5.5, and 6.5 years. They concluded that this finding was broadly consistent with the lexical restructuring model's

claim – however, phonological awareness also predicted vocabulary breadth measured at 5 years. The researchers concluded that a reciprocal relationship between phonological awareness and vocabulary breadth may therefore exist. Rvachew (2006) followed 47 pre-kindergarten students with speech-sound disorders for one year. She found that receptive vocabulary breadth measured in preschool predicted unique variance in phonological awareness measured in kindergarten. The opposite relationship was not detected – that is, phonological awareness was not related to growth in receptive vocabulary.

While these longitudinal studies offer insight into the direction of causality in the relationship between vocabulary breadth and phonological awareness, few studies have provided direct, causal assessments of such through experimental manipulations of key global and/or local factors. Lonigan (2007) reported a study with 286 4.5-year-old preschool children who received nine months of instruction in either vocabulary or phonological awareness or were part of a control group that followed the regular preschool curriculum. At post-test, the group who received the vocabulary training had significant pre-to-post-test changes in expressive vocabulary and phonological awareness. The group who received the phonological awareness training had significant gains in phonological awareness, but not in expressive vocabulary (see also O’Leary, 2017). Lonigan’s (2007) findings perhaps provide the strongest support to date for the lexical restructuring model’s claim that vocabulary growth is causally related to the development of phonological awareness.

In a smaller study, Duff et al. (2008) examined a group of 12 8-year-old struggling readers who did not respond to an intervention targeting letter-sound knowledge and phonological awareness. Following a nine-week intervention period, they found that vocabulary knowledge training coupled with phonological awareness training improved phonemic

awareness in these students more than phonological awareness training without vocabulary knowledge training. The independent effects of vocabulary growth are difficult to disentangle in this particular study, given that the intervention also included elements of phonological awareness training; however, they are somewhat consistent with and support Lonigan's (2007) findings for younger children who received only vocabulary instruction.

Studies have also examined the causal influence of vocabulary growth on phonological awareness in languages other than English. Porta and Ramirez (2020) found that 5.5-year-old Spanish-speaking kindergarteners who received three months of training in vocabulary breadth (with small elements of phonological awareness) showed significant increases on measures of vocabulary knowledge and phonological awareness from pre-to-post-test. Children who received a phonological awareness intervention only showed significant increases in phonological awareness and did not differ from a control group (who followed the regular curriculum) on vocabulary knowledge. Furthermore, post-test gains in phonological awareness were not significantly different between the phonological awareness group and the vocabulary group.

Two studies of 4.5-year-old Dutch-speaking kindergarteners examined the effects of a 6-week vocabulary training program that taught children groups of new similar-sounding words (words that differed by a single phoneme). Van Goch et. al (2014) found that children who received the vocabulary training showed significant pre-to-post-test gains in rhyme awareness, while a control group who received numeracy training did not. Janssen et. al (2015) found that children who received the vocabulary training showed better phoneme blending skills at post-test than a numeracy training control group.

Another study of Dutch-speaking children by deJong and colleagues (2000) found that kindergarten children who received two weeks of phonological sensitivity training performed

better on a post-test nonword learning task than students who received two weeks of conceptual categorization training, in which children were trained to sort real-world objects into categories based on object similarity. However, this was likely not reflective of vocabulary learning from the ambient environment over time as the phonological sensitivity training may well have primed students' attention to the sound structure of the nonwords used in the post-test word learning task. Carroll et al. (2003) also pointed out that the word learning task took place entirely in one session, and children's performance did not correlate with scores on standardized measures of receptive vocabulary. Thus, this study may have been more representative of short-term memory as opposed to processes related to vocabulary acquisition. Given the extremely small sample size in each condition ($N = 14$), and the somewhat convoluted design, this study does not appear to directly bear on the claims under examination in this paper.

In considering the research that has been previously discussed, several longitudinal studies and a small body of experimental research directly examining causality appear to support the overarching claim of the lexical restructuring model that vocabulary growth influences the development of phonological awareness. There are, however, limitations to this research that have yet to be addressed. First, very few studies have examined or isolated the effects of overall vocabulary growth on phonological awareness task performance (cf. Lonigan, 2007). Second, while local factors in the lexical restructuring model (i.e., vocabulary breadth) have been studied in correlational research, local factors (i.e., frequency or neighborhood density) have not been directly manipulated in experimental tasks (cf. Hogan et. al, 2011). Thus, studies that experimentally manipulate familiarity or neighborhood density are needed to further investigate the claims of the lexical restructuring model, as well as the developmental origins of the phoneme for implicit and explicit phonological processing tasks.

Word Learning in Early Elementary School Children

Word learning is an implicit phonological processing task that, at the basic level, involves the creation of a new lexical representation containing the phonological form of the word, and a new semantic representation containing information related to the word's meaning (e.g. Gupta & MacWhinney, 1997). These representations are associated with one another and then stored in long-term memory with existing representations (Storkel, 2004). Across development, most words are learned incidentally through exposure to everyday spoken language (e.g., Ma et. al, 2011). Consequentially, variations in the frequency and quality of spoken language exposures are a particularly strong predictor of children's concurrent and subsequent vocabulary size (e.g., Goodman et. al, 2008; Storkel, 2001).

Young children undergo an initial vocabulary growth spurt at approximately two years of age, and word learning trajectories continue to rapidly increase during the preschool years and reach their peak in second grade (Biemiller, 2005; Biemiller & Slonim, 2001). Biemiller (2003) estimates that from the time children are 1 year old to the end of second grade (approximately 8 years of age), approximately 860 root words are acquired per year. Toddlers and young children may incidentally learn many of these new words through a process known as fast mapping (Carey & Bartlett, 1978). Fast mapping describes the process by which children rapidly infer the meaning of a new word encountered in spoken language by using contextual and linguistic information through as little as one exposure (Dollaghan, 1987).

Neighborhood Density and Word Learning

Language input is not the only factor that influences word learning, however. As with other aspects of phonological processing, lexical characteristics of words themselves, such as neighborhood density, have been shown to influence word learning. Several popular theories of

word learning hypothesize that the strength of the associations built between lexical and semantic representations are influenced by neighborhood density (e.g., Gasser & Smith, 1998; Gupta & MacWhinney, 1997). The activation of existing lexical representations is proposed to strengthen a newly created lexical representation and facilitate its transfer to long-term memory (Storkel, 2004; Jusczyk et. al., 1994). Adlof & Patten (2017) found that after controlling for age, receptive vocabulary knowledge predicted unique variance in children's learning of nonword-nonobject pairs that were held constant in neighborhood density. This may suggest that children with greater vocabulary knowledge had more existing representations available to support word learning than children with relatively less vocabulary knowledge. Likewise, children may also learn words from dense neighborhoods more readily than words from sparse neighborhoods, given that more sounds and sound patterns exist in the lexicon for dense words (Lindblom, 1992).

Many of the key findings surrounding neighborhood density and word learning in younger children have come from the work of Storkel and colleagues. Examinations of neighborhood density and word learning have typically occurred alongside that of phonotactic probability, which is a similar (albeit distinct) lexical characteristic. Phonotactic probability refers to the likelihood of the occurrence of a sound sequence within a given word (Storkel & Lee, 2011), and while it has been shown to play a role in word learning, it is not relevant to the current study. Neighborhood density and phonotactic probability are highly correlated, such that high-probability sound sequences tend to reside in dense neighborhoods, and low-probability sound sequences tend to reside in sparse neighborhoods (Vitevitch et al., 1999). Studies of novel word learning have frequently examined the combined effects of phonotactic probability and neighborhood density, and have generally found that high-probability-high-density words are

learned more accurately than low-probability-low-density words in experimental settings (e.g., Storkel, 2001; 2003; Storkel & Maekawa, 2005) and in naturalistic settings (e.g., Storkel, 2004).

Other studies have examined the independent effects of neighborhood density on children's word learning. For example, 3–5-year-old children learned dense pseudowords more accurately than sparse pseudowords when phonotactic probability was held constantly high (Hoover et. al., 2010). Storkel and colleagues (2013) taught 3-5-year-old children nonword-nonobject pairs that increased incrementally in neighborhood density while phonotactic probability was held constant. They found that word learning followed a linear trend as neighborhood density increased and concluded that "...the relationship between word learning and density is best described as a continuous linear function" (p.1697). Overall, evidence from these studies indicates that increasing neighborhood density facilitates the learning of new words in young children.

The overall advantage for learning words from dense neighborhoods appears to remain stable across development. Storkel et. al (2006) found that adults who participated in a nonword-nonobject learning task identified nonobjects with nonword names from dense neighborhoods more accurately than those from sparse neighborhoods. Therefore, the processes underlying word learning may be similar in children and adults. However, the magnitude of the advantage for dense word learning may decrease across development with continued vocabulary growth, as similarity relations among items in sparse and dense areas of the lexicon may become more equivalent. A key study by Storkel & Hoover (2011) bears on this issue. They examined how manipulations of part-word neighborhood density (vowel-consonant clusters) across nonwords may affect word learning in 3-6-year-old children. They found that children higher in expressive vocabulary knowledge showed stronger learning performance on words containing sparse vowel-

consonant clusters than children lower in expressive vocabulary knowledge. Children with higher vocabulary knowledge may have had more neighbors available to facilitate learning new words from sparse neighborhoods. Thus, these results support the proposition that the advantage for dense word learning may decrease with increasing vocabulary breadth.

The idea that neighborhood density and existing vocabulary knowledge may influence the acquisition of new words aligns with the claims made by the lexical restructuring model. Learning new words may be supported by the segmental structure of existing lexical representations. Novel words that activate dense neighborhoods of words may be learned more easily than words from sparse neighborhoods, and children with greater vocabulary breadth may be better able to acquire new words from sparse neighborhoods because a greater number of segmentalized representations exist in these areas to support lexical acquisition (Jusczyk et al., 1994; Storkel, 2004). More detailed representations could help to maintain novel sound sequences in working memory and thus result in the creation of more complete and accurate lexical representations in long term memory (Bowey, 2001; Metsala et al., 2009; Storkel et al., 2013). Therefore, as more existing lexical representations are activated, or as the segmental detail of existing representations increases, newly created lexical representations may become more robust. More research is needed, however, to causally examine the role of lexical restructuring and segmental processing in word learning.

Word Learning and Nonword Repetition: Interrelated Constructs

One area of the literature that is directly related to word learning is that of nonword repetition, which is an implicit phonological processing task suggested to reflect individual differences in the precision and quality of an individual's lexical representations (Bowey, 2001; Coady & Evans, 2008). Gathercole (2006, p. 513) has suggested that nonword repetition may be

“...the most effective predictor of language learning ability that is currently known”. Word learning and nonword repetition share significant overlap in that they both rely on existing lexical representations (Munson, 2006) and require accurate speech perception, temporary and/or permanent storage of novel sound sequences, and retrieval from memory (Aguiar & Brady, 1991; Gray et al., 2014). Bowey (2006) states that “...relationships between nonword repetition and word learning may be reciprocal, with vocabulary level affecting children’s ability to segment nonwords efficiently and retain them in memory” (p. 548). Indeed, nonword repetition is highly correlated with word learning capabilities in young children (e.g., Gathercole et al., 1992; Gathercole et al., 1997; Gupta, 2003), as well as with vocabulary size (e.g., Baddeley et al., 1998; Gathercole & Adams, 1993; Metsala, 1999; Papagno & Vallar, 1995).

These relationships between nonword repetition and vocabulary size and word learning have been a subject of debate among researchers and have led to two primary accounts. The first account, known as the phonological storage capacity account (see Baddeley et al. 1998; Gathercole, 2006; Gathercole et al., 1999). This position argues that individual differences in word learning, nonword repetition, and overall vocabulary size are attributable to individual differences in the capacity of the phonological loop component of working memory (hereafter referred to as phonological working memory). Phonological working memory is proposed to function as a language-learning device that serves “to store unfamiliar sound patterns while more permanent memory records are being constructed” (Baddeley et al., 1998, p. 158). Baddeley and colleagues (1998) have suggested that nonword repetition tasks provide a relatively pure measure of phonological short-term memory capacity because novel words do not have an existing representation in lexical memory, and therefore lexical knowledge does not intrude on performance (see also Gathercole & Baddeley, 1989, and Gathercole et al., 1992).

More relevant to the current study is a second account of the relationship between vocabulary size and nonword repetition and word learning, known as the lexical reorganization account (Metsala, 1999; see also Bowey, 2001; Edwards et al., 2004; Snowling et al., 1991). According to this position, nonword repetition is argued to be a measure of phonological sensitivity. Vocabulary growth leads to lexical representations that have greater detail, segmental structure, and connection strength to other lexical representations, which in turn facilitate nonword repetition and word learning (Metsala & Chisholm, 2010). Individual differences in the segmental structure of existing lexical representations account for the relationship between nonword repetition and vocabulary size, thereby mediating this relationship (Metsala, 1999).

Implicit in the lexical restructuring account is that nonword repetition tasks are influenced by existing lexical knowledge, and thus are not a pure measure of phonological working memory capacity. Several studies have supported this position. Snowling et al. (1991) first proposed that knowledge of the structure of words could be used to support performance on nonword repetition tasks and when learning new words. Gathercole (1995) found that words rated higher in wordlikeness were repeated more accurately than words rated lower in such. Wordlikeness ratings have been demonstrated to be a reliable index of neighborhood density because they are associated with the number of real words with similar phonological forms that are already known (Metsala, 2011b; see Bailey & Hahn, 2001). Metsala (1999) found that phonological awareness contributed unique variance to vocabulary size beyond that accounted for by nonword repetition in a sample of four- and five-year-old children. However, nonword repetition did not account for unique variance when entered into a regression after phonological awareness. These results were interpreted as suggesting that phonological working memory capacity was not implicated in the association between nonword repetition and vocabulary but

rather the development of segmental lexical representations. In a longitudinal study of kindergarten children, Bowey (2001) found that nonword repetition and phonological awareness contributed unique variance to vocabulary knowledge at time one, but nonword repetition did not account for additional variance beyond that accounted for by phonological awareness at time two, supporting Metsala's (1999) conclusions. Taken together, these results support the argument that individual differences in existing lexical knowledge intrudes on word learning and nonword repetition task performance.

While correlated factors have been examined to better understand the nature of nonword repetition and explain additional variance in task performance, few studies have directly examined how individual differences in the segmental structure of existing lexical representations might influence word learning and nonword repetition. As with other phonological processing tasks, examinations of performance across stimuli that vary in neighborhood density might be revealing in this regard. In particular, the ability to repeat nonwords from sparse neighborhoods has been argued to require more autonomous and robust individual segments in lexical memory (e.g., Metsala, 2011b; Munson et al., 2005). Therefore, individual differences in such may be a strong indicator of the extent to which lexical restructuring has taken place (Walley et al., 2003).

Few studies have examined the influence of neighborhood density on nonword repetition. Dollaghan et al. (1993; 1995) found that repetition accuracy was higher for nonwords containing a stressed real-word syllable versus a stressed nonword syllable, leading to the hypothesis that lexical knowledge and neighborhood density do indeed play a role in nonword repetition task performance. Edwards et al. (2004) and Munson et al. (2005) found that children aged 3-8 years old were more accurate at repeating two-phoneme sequences high in phonotactic probability than

sequences low in phonotactic probability. Furthermore, this advantage for repeating high-probability sequences decreased as vocabulary knowledge increased. The authors concluded that the effects of phonotactic probability on nonword repetition decrease as lexical representations become more phonemically organized, and that accurate repetition of low-probability nonwords relies on well-specified, segmental lexical representations of words associated with larger vocabulary knowledge (Edwards et. al., 2004; Munson et. al., 2005). As previously discussed, phonotactic probability and neighborhood density are highly related constructs, and given that they are both proposed to arise from an individual's lexical knowledge, a similar relationship between neighborhood density and vocabulary knowledge may be expected in examinations of nonword repetition. Metsala & Chisholm (2010) found that 3-7-year-old children were more accurate at repeating syllables from dense neighborhoods than syllables from sparse neighborhoods in a multisyllabic nonword repetition task, and that the magnitude of this advantage was stronger for children lower in vocabulary knowledge than for children higher in vocabulary knowledge.

Overall, these results suggest that neighborhood density does influence nonword repetition accuracy and aligns with the pattern of results reported in Storkel and Hoover's (2011) study of word learning. That is, the advantage for repeating syllables and learning words from dense neighborhoods may decrease as neighborhood density becomes more equivalent across words through continued vocabulary growth. For younger children in the initial elementary school grades, further examinations of neighborhood density in the repetition of sparse and dense multisyllabic nonwords – specifically, the capacity to repeat nonwords from sparse neighborhoods - may help to reveal how individual differences in lexical restructuring contribute to word learning.

Word Reading and Phonological Processing

One aim of literacy research has been to delineate the role of implicit and explicit phonological processing abilities in the acquisition of word reading skills (e.g., McBride-Chang et al., 1997). Poor readers have been found to have marked difficulties with phonological processing (e.g., Bruck, 1992; Metsala, 1997), and studies on typically developing children have found strong associations between phonological processing tasks and word reading skills (Metsala et al., 2009). As previously mentioned, literacy development strongly depends on the ability to access and manipulate the sound structure of language at the phonemic level (Brady & Shankweiler, 1991) and phonemic awareness is one of the strongest predictors of word reading (Wagner & Torgesen, 1987). Therefore, segmental processing/representation in young children may be a potent predictor of word reading abilities.

Several studies have found evidence that the relationship between implicit phonological processing tasks (such as spoken word recognition) and word reading is fully mediated by phonological awareness (e.g., Chaney, 1994; Garlock et al., 2001; McBride-Chang et al., 1997; Metsala et al., 2009). Garlock et al. (2001) found that the recognition of earlier acquired words from sparse neighborhoods contributed unique variance to concurrent phonological awareness in preschoolers and kindergarteners, which in turn predicted their word reading skills. In a follow-up study to that of Garlock and colleagues (2001), Metsala et al. (2009) found that the recognition of words from sparse neighborhoods predicted subsequent variance in children's phonological awareness one year later, which in turn contributed unique variance to word reading skills. These findings match the pattern of results found by other studies (e.g., Chaney, 1994; McBride-Chang et al., 1997), suggesting that developmental advances in representations of spoken words contribute to word reading indirectly through phonological awareness.

Other studies, however, have found evidence that segmental representation contributes directly to word reading skills in children. Metsala (1997) showed that the recognition of words from sparse neighborhoods predicted unique variance in word reading beyond that accounted for by phoneme awareness in both typically developing children and children with reading disabilities - however, recognition of words from dense neighborhoods did not. Metsala (2011b) found that first grader's repetition of nonwords rated low in wordlikeness during the fall predicted unique variance in spring word reading skills - beyond that accounted for by vocabulary, phonological short-term memory, phonological awareness, and initial word reading skills from the fall. These results, along with others (e.g., Chiappe et al., 2007), suggest that developmental advances in representations of spoken words directly contribute to word reading.

While it is unclear whether this relationship may be direct or indirect, these results nonetheless support the claim that segmental representation/processing contributes to word reading skills in young children (Metsala & Walley, 1998). They also provide further evidence that task performance on stimuli from sparse neighborhoods may be a strong indicator in the extent of lexical refinement (Metsala et al., 2009). Children with less robust vocabulary knowledge may lack the segmental representation needed to phonemically process words from sparse neighborhoods. Because these children know fewer word neighbors overall, lexical reorganization for words residing in sparse neighborhoods may be particularly affected and processing may be governed by lexical characteristics for a longer period of time (Metsala, 2011a). Consistent with this argument, Brown (1997) found that a computer simulation of reading development displayed significant reading impairments akin to children with reading disabilities when the model's lexical representations were less segmental. As such, examinations of performance on phonological processing tasks containing stimuli that vary in neighborhood

density have the potential to reveal how segmental processing/representation might contribute to word reading in children.

The Current Study

In this study, children in the early elementary school years completed a battery of tasks designed to examine several claims made by the lexical restructuring model and add to the small body of research that moves beyond correlational evidence. An experimental word learning task was carried out to introduce children to 18 novel spoken words (nonwords were used in the word learning task) paired with line drawings of novel objects (non-objects, as used in past research; Kroll & Potter, 1984; for examples, see Storkel et al., 2013, and Storkel & Lee, 2011). There were three categories of nonwords that children learned in this spoken word learning task: those that resided in i) phonologically sparse neighborhoods, ii) phonologically dense neighborhoods, and iii) words from sparse phonological neighborhoods that underwent an experimental manipulation to build-up the number of phonological neighbors the child had heard. These last words are referred to as “transitioning” from sparse-to-dense phonological neighborhoods as children were introduced to six similar-sounding nonword neighbors in an attempt to experimentally affect lexical restructuring – or realistically, to direct more attention to the internal structure of these nonwords - a central process when words become segmentally restructured or are stored in the lexicon with words that share segmental/phonemic overlap.

Using nonwords is similar to previous research that has examined word learning in children (e.g., Storkel et al., 2013; Storkel & Hoover, 2011; Storkel & Lee, 2011) and has several advantages. First, nonwords may help to isolate the effects of neighborhood density by controlling for other lexical characteristics, such as word frequency and age of acquisition. Second, using nonwords ensures that stimuli are novel to all participants. These advantages

allow for an examination of whether a word has been learned, or to some extent, begun the transfer to long-term memory, by using recall and recognition tasks.

In this study, responses on the word learning task, as well as on a phoneme awareness task for the nonwords, were compared across the three nonword conditions. A nonword repetition task containing items that differed in neighborhood density was also used to examine how the repetition of nonwords from sparse and dense neighborhoods may be related to word learning. Lastly, this study sought to examine how responses to words from sparse and dense neighborhoods on the experimental phonemic awareness task may be uniquely associated with word reading. The four research questions follow next.

Research Question 1

The first research question examined whether children show higher performance on the word learning task for the sparse-to-dense nonwords (i.e., the nonwords that had phonological neighbors introduced before their learning trial). I predicted that the sparse-to-dense nonwords that had neighbors introduced would yield higher performance on the word learning task than the sparse nonwords. Specifically, introducing these phonological neighbors was expected to direct the child's attention to the internal structure of these "transitioning" nonwords. This hypothesis is based upon and extends the idea that existing lexical representations will strengthen a newly created lexical representation as a word is being learned (e.g., Adlof & Patten, 2017; Storkel, 2004; Storkel et al., 2013; see also Jusczyk et. al, 1994).

Research Question 2

The second research question investigated if there was an effect of neighborhood density on phonemic awareness from pre-to-post-test for the nonwords that had neighbors introduced. I predicted that words in the sparse-to-dense category would show a pronounced improvement

from pre-to-post-test. Specifically, gains from pre-to-post-test would be higher for these sparse-to-dense words than for words in the sparse and dense conditions. This prediction is based on the lexical restructuring model's claim that as children learn more words, words residing in increasingly crowded areas of the lexicon become more segmental/phonemic, thereby allowing conscious access to their phonemic structure for use in phonemic awareness tasks (Metsala & Walley, 1998; see also Hogan et al., 2011). As stated previously, the introduction of phonologically similar neighbors was expected to draw more attention to the internal structure of these sparse-to-dense items. Therefore, phoneme awareness performance should be facilitated from pre-to-post-test for those nonwords that have neighbors introduced.

Research Question 3

The third research question asked whether repetition of nonwords from sparse neighborhoods would account for unique variance in word learning. I predicted that the repetition of nonwords from sparse neighborhoods would predict unique variance in word learning, after controlling for grade and the repetition of dense nonwords. Nonword repetition has been demonstrated to share a strong association with word learning (Gathercole et al., 1992). Furthermore, the ability to accurately repeat less frequent or sparse sound sequences and to learn new words both rely on more robust, segmental representations of spoken words in lexical memory (e.g., Bowey, 2001; Metsala, 1999; Metsala & Chisholm, 2010; Munson et al., 2005). Thus, individual differences in the capacity to repeat sparse sound sequences may be a particularly strong predictor of children's ability to learn new words.

Research Question 4

The final research question examined if phonemic awareness for sparse nonwords predicts unique variance in word reading. I predicted that phonemic awareness performance for

sparse nonwords would predict unique variance in word reading – beyond that already accounted for by grade, phonemic awareness performance for dense nonword items, and general phonemic awareness. Individual differences in processing nonwords from sparse neighborhoods may be particularly salient during the early school years, as these neighborhoods are not proposed to become more segmental or phonemically organized in the lexicon until relatively later in development (Metsala, 1997; Metsala et al., 2009; Storkel, 2006; for a review, see Metsala, 2011a). Therefore, the ability to explicitly process sparse nonwords may be uniquely associated with learning to read words, which partly relies on access to the phonemic level of speech processing (for similar findings see Garlock et al., 2001; Metsala, 2011b).

It should be noted, that for each of the above hypotheses, I expected the effects of neighborhood density to be more pronounced for children in the younger group, consistent with previous research (e.g., Hogan et. al., 2011; Metsala et. al., 2009; Metsala & Chisholm, 2010; Storkel, 2006; see Metsala, 2011a for a review). As previously discussed, younger children are not as far along in their lexical restructuring or reorganization concerning phonemic representations than are older children.

Methodology

Participants

The participants in this study were early elementary school children in grades primary, one, and two. They were recruited from three schools within a Regional Centre for Education in Nova Scotia. There were 62 participants in total (36 girls; 25 boys; gender information was unavailable for 1 participant). Two additional children requested to discontinue the study and their data is not included. There were 29 participants in grade primary (16 girls; 13 boys) with a mean age of 5 years and 7 months (range = 5 years and 1 month – 6 years and 4 months); 18 children in grade

one (10 girls; seven boys; sex unconfirmed for one participant) with a mean age of 6 years and 8 months (range = 6 years and 1 month – 6 years and 11 months); and 15 children in grade two (10 girls; five boys) with a mean age of 7 years and 8 months (range = 6 years and 6 months – 8 years and 10 months). Due to the lower number of participants in grades one and two, for all analyses, these students were combined into a first- and second-grade group ($n = 33$; $M_{\text{age}} = 7$ years, 1 month; range = 6 years, 1 month – 8 years, 10 months).

Procedure

The data analyzed in this study was part of a collaborative research project by Dr. Metsala and Dr. Robertson and ethics was completed through each of their University's Ethics Review Boards. Ethical approval was obtained from the Mount Saint Vincent University Research Ethics Board for secondary use of data in this thesis.

All students who returned signed consent forms were eligible to partake in this study, and each child's assent was obtained before they participated in each testing session. Children completed three testing sessions in total, each spaced one week apart. All sessions were recorded using a handheld voice recorder. After completing each session, children received a small token (such as a sticker or pencil) to thank them for participating.

Nonword Stimuli for the Word Learning Task

A total of 18 one-syllable nonwords were created for the word learning task. These nonwords fell into the following categories: 6 items from sparse neighborhoods, 6 items from dense neighborhoods, and 6 sparse-to-dense items. A relatively larger number of nonwords were created and then all were submitted to two online neighborhood density calculators — one a model of children's lexicons (Storkel & Hoover, 2010) and the second a model of adults' lexicons (Aljasser & Vitevitch, 2022). These were used to calculate the average number of

neighbors for each nonword. Following this, items with many neighbors and items with fewer neighbors were identified as candidates for each of the three categories. The final items were selected by matching, as best as possible, for equal numbers of the type of initial and final consonant sound (e.g., fricative and affricatives, liquids, and stop sounds). The selected nonword items were assigned to a category based on the online model of the child lexicon (Storkel & Hoover, 2010) after confirming that they did not conflict with the calculations provided by the adult model (Aljasser & Vitevitch, 2022). For a list of the nonwords by condition, see Appendix A. The means and standard deviations for words in the sparse, dense, and sparse-to-dense conditions are reported in Appendix B. Based on the child calculator (Storkel & Hoover, 2010), the sparse, sparse-to-dense, and dense conditions had an average of 3.5, 4.00, and 14.17 phonological neighbors, respectively.

Nonword Learning Task: Learning Phase

To introduce the nonword learning task, children were told that they would be learning the names of some objects that they had not heard of or seen before, and that these objects were used by the rock people; that is, the fictitious characters depicted in the drawings children would be viewing. Children were told to pay close attention to the names of these unfamiliar objects because they would be required to remember them when asked later. Children were also told that they would be repeating the names of some of the rock people they would meet, but that they would not have to remember those names (see the description of sparse-to-dense trials below for further explanation).

During each trial, students participated in the activities while wearing headphones that presented all of the verbal stimuli from audio files on a tablet, and viewed visual stimuli in a binder that was manipulated by a research assistant. The word learning task is discussed next,

along with variations in stimuli presentation for items in the sparse and dense nonword learning trials versus the sparse-to-dense nonword learning trials. These learning trials were interspersed with one another on each day of testing. On day 1, children learned the first 9 nonwords, and on day 2, they learned the remaining 9 nonwords.

Before the start of the word learning task on each day, children practiced one item together with the tester. A correct response on this practice item was required before proceeding with the task. For students who did not initially provide a correct response on this practice item, corrective feedback was given until a correct response was provided.

For each sparse nonword, dense nonword, and sparse-to-dense nonword (six of each type), children were presented with a picture of a nonobject line drawing on a page in an easel-type setup (the paired nonword-nonobject drawings are shown in Appendix A) and participated in the following interactions, receiving prompts or instructions over their headphones.

1. Recorded voice: “This is a word to learn for later. Listen close. This is a yib. Point to the yib.” Children then pointed to the single nonobject line drawing displayed on a page. Children who did not do so were shown by the examiner how to point to the object.
2. Recorded voice: “Yes, that is a yib. Say the word yib.” Children’s repetition of the nonword name was then recorded as correct or incorrect by the examiner.
3. Recorded voice: “Which one is the yib?”. Children were required to identify the target nonobject line drawing now on a page also displaying two distractor items. The examiner recorded their response as correct or incorrect.

4. Recorded voice: “That is the yib. Say the word yib.” Regardless of the child’s response in Step 3, the examiner pointed to the correct nonobject as the recording played.

This was the conclusion of word learning trails for the items in the sparse and dense conditions. The sparse-to-dense condition differed with the following manipulations. Before each sparse-to-dense nonword learning trial, to introduce similar sounding neighbors, children participated in these additional interactions and received the following instructions over their headphones. The examiner turned the page as each new rock person was introduced.

1) Recorded voice: “Here are some rock people. Listen closely to their names.”

2) Recorded voice: “This is teeg. Say teeg. Bye teeg.”

3) Recorded voice: “This is weeg. Say weeg. Bye weeg.”

4) Recorded voice: “This is feek. Say feek. By feek.”

5) Recorded voice: “This is feeb. Say feeb. Bye feeb.”

6) Recorded voice: “This is deeg. Say deeg. Bye deeg.”

7) Recorded voice: “This is feep. Say feep. Bye feep.”

Thus, for each sparse-to-dense item, children repeated the names of six rock people — all of which were phonological neighbors of the target item.

Following the word learning trials for 9 items each day, there was an immediate word recognition test (see measures section).

Task Order

The order of the tasks on each day of testing was as follows.

Day 1

- i. Each child completed the pre-test phoneme blending task for all 18 target nonwords.

- ii. Children completed the nonword learning task for the first nine nonword items.
- iii. Children completed an immediate recognition and recall task immediately following the learning trials (see measures below).
- iv. Each child completed the post-test phoneme blending task for the nine nonwords taught on day 1.

Day 2

- i. Each child completed delayed recall and recognition tests for the nine nonwords taught on day 1.
- ii. Children completed the nonword learning task for the remaining nine nonword items.
- iii. Children completed an immediate recognition and recall task immediately following the learning trials.
- iv. Each child completed the post-test phoneme blending task for the nine nonwords taught on day 2.
- v. Each child completed the *Word Identification* subtest from the Woodcock Reading Mastery Test – Third Edition (WRMT-III; Woodcock, 2011).

Day 3

- i. Each child completed delayed recall and recognition tasks for the nine nonword items learned on day 2.
- ii. Each child completed the *Elision* subtest from the Comprehensive Test of Phonological Processing – Second Edition (CTOPP-2; Wagner et. al., 2013), an experimental nonword repetition task, the Peabody Picture Vocabulary Test – Fifth Edition (PPVT-5; Dunn & Dunn, 2019), and an experimental odd-word-out vocabulary task.

In the current study, the PPVT-5, the odd-word-out task, and the immediate recall and delayed recall and recognition tests are not included or analyzed and are not further described. The immediate recall (a production task) and delayed tasks were too difficult and showed floor effects.

Measures

Pre-and-Post-Test Phonemic Awareness: Nonword Blending for all 18 Test Items

There was a pre-test phoneme blending task for the 18 nonwords in the learning trials. Over headphones, children listened to a sequence of three individual phonemes and were required to blend the sounds together into a nonword. For this task, the child was told to listen to the sounds that a rock person named Bark said, and then to put them all together and say what made-up word the sounds made. Two trials with corrective feedback were conducted before proceeding to the 18 target nonwords. Items were scored as correct or incorrect.

For the post-test phoneme blending tasks, children completed the same task, but only for the nine nonword items taught during the learning trials for that day. The same procedure used during the pre-test phoneme blending task was followed.

Nonword Learning Task: Immediate Recognition

On the two days with word learning trials, children completed a recognition test immediately following the learning trials. Children were presented with three of the nonword-nonobject drawings on a page and were asked to point to the correct item corresponding to a spoken nonword.

General Phoneme Awareness

As a measure of general phonological awareness, each participant completed the *Elision* subtest from the CTOPP-2 (Wagner et al., 2013). This task required children to delete a unit of

sound from a spoken word. Initial items start with larger units of sound to be deleted (e.g., “Say the word ballpark. Now say the word ballpark without saying ball”). Items progress to the phoneme-level (e.g., “Say cat without saying /k/”). Manualized testing procedures were followed, with testing discontinued after three consecutive incorrect responses after the tenth item.

Nonword Repetition

Children listened to a multisyllabic nonword presented over the headphones and immediately repeated back the nonword. There were 8 three- and 8 four-syllable nonwords in this task. For nonwords of each length, half of the items contained two target syllables from dense word neighborhoods and the remaining half contained two target syllables from sparse word neighborhoods. The target syllables occupied the first and third syllables within the nonwords, and were comprised of C-V-C, C-V-C-C, or C-V-V-C clusters. Non-target syllables were the second and fourth syllables within the nonwords. The second syllables were vowels or V-C pairs, while the fourth syllables were V-C, C-V, and V-C-C clusters. Examples of items in the sparse condition are ‘najapesh’ (nāj – ā – pēsh) and ‘powmugebic’ (powm – ů – gēb – ic). Examples of items in the dense condition are ‘sugatem’ (sŭg – ā – tēm) and ‘widapatly’ (wīd – ā – pāt – ly). In both the sparse and dense conditions, the target syllables were also the stressed syllables, and stress placement was consistent across conditions (see Dollaghan et. al., 1995; 1993). Two practice items (a one-syllable nonword and a three-syllable nonword) were completed with corrective feedback as needed. Neighborhood density for the constituent syllables in each nonword was computed through online calculators based on the child corpora (Storkel & Hoover, 2010) and the adult corpora (Aljasser & Vitevitch, 2022). Items were scored as correct if the child accurately repeated both target syllables.

Word Reading

To assess word reading skills, each child completed the *Word Identification* subtest of the WRMT-III (Woodcock, 2011). Children were required to read words of progressing difficulty. Manualized testing procedures were followed, with testing discontinued after four consecutive errors.

Results

Data Preparation

Prior to analysis, data were screened for outliers and other inconsistencies. Only 52 participants completed the nonword repetition task and this data was not replaced. The repeated measures Analysis of Variance (ANOVA) tests were performed on raw scores. Skewness and kurtosis values for the variables included in the ANOVAs were all within the normal range (Hair et al., 2010). The only exceptions were for pre-test phoneme blending for sparse items and sparse-to-dense items in the younger group of students. These deviations from normality were addressed through a supplementary analysis (see results for Research Question 2 below).

All regression analyses were performed on Z-scores that were calculated across the entire sample. Skewness and kurtosis values for all regression variables were within the normal range (Hair et al., 2010). The absence of multivariate outliers was confirmed by calculating Mahalanobis distances for each variable and using $p = 0.001$ as a cutoff to detect outliers (Leys et al., 2018). All variance inflation factors (VIFs) were below 3.67, indicating that multicollinearity was not an issue in the regression models (Tabachnick & Fidell, 2007). Observations of partial regression plots also revealed linear relationships between all predictor and criterion variables, satisfying the linearity assumption.

Research Question 1: Do children perform higher on the word learning task for nonwords with the neighbors introduced (sparse-to-dense) than for the sparse nonwords?

The means and standard deviations for all measures by age group are reported in Table 1. Given the relatively small sample size in each group of students, two separate one-way ANOVAs were conducted for each group. This approach was chosen to reduce the number of cells in the analysis and thereby maintain statistical power. A one-way repeated measures ANOVA was conducted to examine the effect of neighborhood density (sparse, sparse-to-dense, dense) on younger students' immediate recognition of words introduced through the word learning task ($n = 29$). Mauchly's test of sphericity was performed and satisfied $\chi^2(2) = 3.20, p = 0.202$. The analysis revealed a statistically significant main effect of density, $F(2,56) = 10.377, p < .001, \eta_p^2 = 0.270$.

Table 1.

Means and standard deviations for raw scores on measures in this study.

Measure	Younger Group ($n = 29$)		Older Group ($n = 33$)	
	Mean	<i>SD</i>	Mean	<i>SD</i>
WL Sparse	2.59	1.27	2.50	1.41
WL Sparse-to-Dense	1.41	0.95	1.61	0.90
WL Dense	1.62	1.18	1.39	1.09
WL Total Score	5.62	2.26	5.50	2.82
Pre-PA Dense	0.79	1.45	2.94	1.85
Pre-PA Sparse	0.55	0.95	2.67	1.95
Pre-PA Sparse-to-Dense	0.59	1.21	3.24	1.84
Post-PA Dense	1.55	2.05	3.76	1.99
Post-PA Sparse	1.52	1.70	3.49	1.89
Post-PA Sparse-to-Dense	2.07	2.28	4.03	1.85
NWR Dense	4.92	2.16	6.21	1.77
NWR Sparse	3.56	1.85	4.25	1.99
Word ID	2.10	3.14	12.30	9.06
CTOPP-2 Elision	9.00	4.87	13.21	8.71

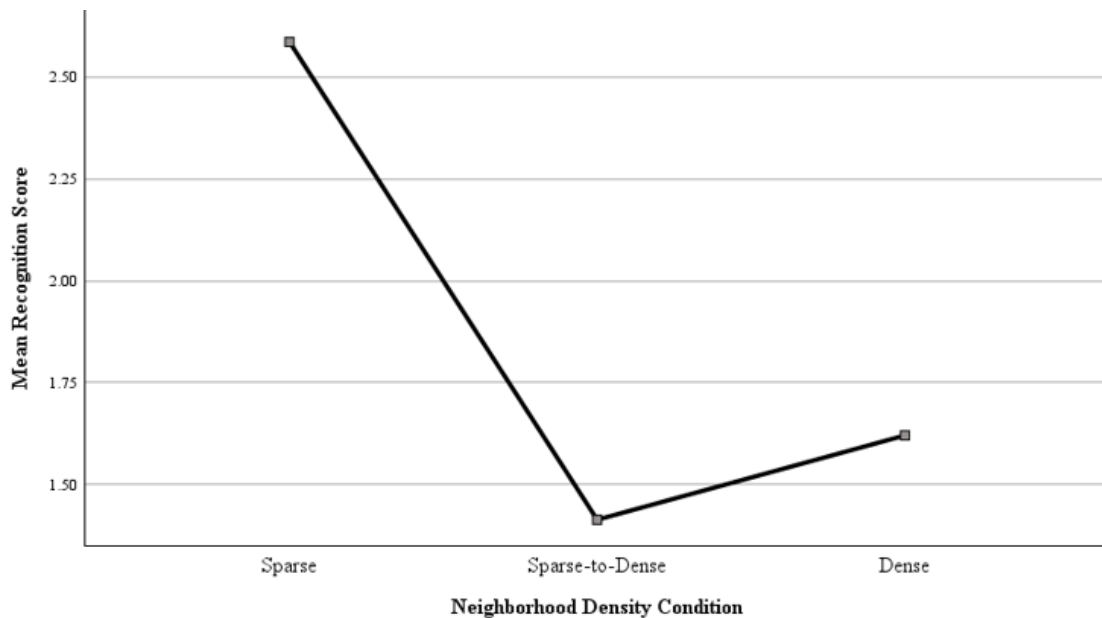
Note. WL = word learning; PA = phonemic awareness; Pre = pre-test; Post = post-test; Word ID = Word Identification subtest (Woodcock Reading Mastery Tests – Third Edition); CTOPP-2 Elision = Comprehensive Test of Phonological Processing – Second Edition elision subtest.

Pairwise comparisons revealed that the mean score in the sparse condition ($M = 2.586, SE$

= 0.236) was significantly higher than the mean scores in the sparse-to-dense ($M = 1.414$, $SE = 0.176$) and dense conditions ($M = 1.621$, $SE = 0.219$). No significant difference was detected between the sparse-to-dense and dense nonword conditions (all pairwise comparisons were done using tests of Least Significant Difference to reduce the risk of Type II error associated with small group sizes; Howell, 2019; Sullivan et. al., 2016). Overall then, students in the younger group showed better word learning for items in the sparse condition than those in the sparse-to-dense and dense conditions (see Figure 1), and this effect was associated with a large effect size.

Figure 1.

Word Learning Recognition Performance by Density Condition in the Younger Group.



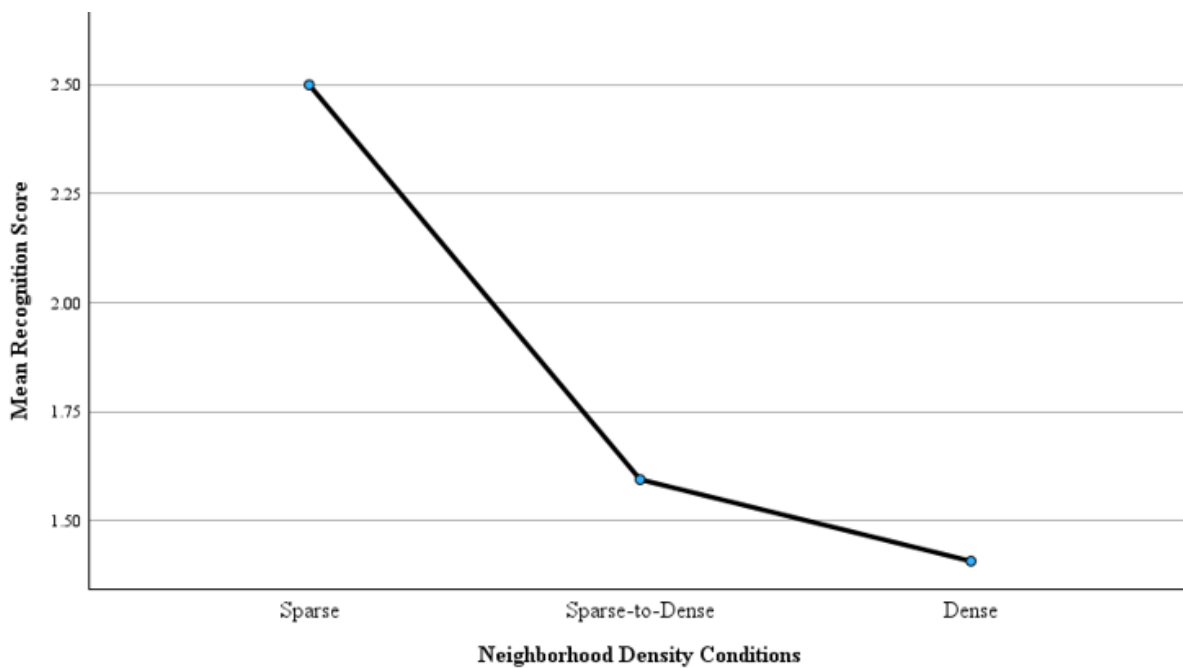
The same analysis was conducted with the group of students in first and second grade ($n = 33$). Mauchly's test of sphericity was performed and satisfied $\chi^2(2) = 2.162$, $p = 0.339$. Analysis revealed a significant main effect of density, $F(2, 64) = 17.544$, $p < .001$, $\eta_p^2 = 0.354$.

Pairwise comparisons showed that the mean recognition score in the sparse condition ($M = 2.545$, $SE = .247$) was significantly higher than the mean scores in the sparse-to-dense ($M =$

1.606, $SE = 0.157$) and dense conditions ($M = 1.394$, $SE = 0.189$). There was no significant difference between the sparse-to-dense and dense nonword conditions. Similar to the younger group, the group of older students showed better learning of nonwords in the sparse condition compared to the sparse-to-dense and dense conditions (see Figure 2), and this effect was associated with a large effect size.

Figure 2.

Word learning Recognition Performance by Density Condition in the Older Group.



Research Question 2: Is there an effect of neighborhood density on phonemic awareness from pre-to-post-test for the nonwords that had neighbors introduced (i.e., sparse-to-dense nonwords)?

To answer the question of whether the introduction of neighbors affected the phoneme blending performance, a two-way repeated measures ANOVA was conducted with the group of younger students first. The analysis examined the effects of time (pre-test, post-test) and neighborhood density (sparse, dense, sparse-to-dense) on phoneme blending accuracy. Mauchly's

test indicated that the assumption of sphericity was met for the interaction term $\chi^2(2) = .008, p = 0.996$. Results showed a significant main effect of time $F(1, 28) = 25.556, p < .001, \eta_p^2 = 0.477$ and a Time x Density interaction $F(2, 56) = 4.465, p = .016, \eta_p^2 = 0.138$. Overall, the effect of time showed that participants scored higher on post-test blending than on pre-test blending. The interaction, however, indicated that the amount of improvement from pre-to-post-test differed depending on the density condition.

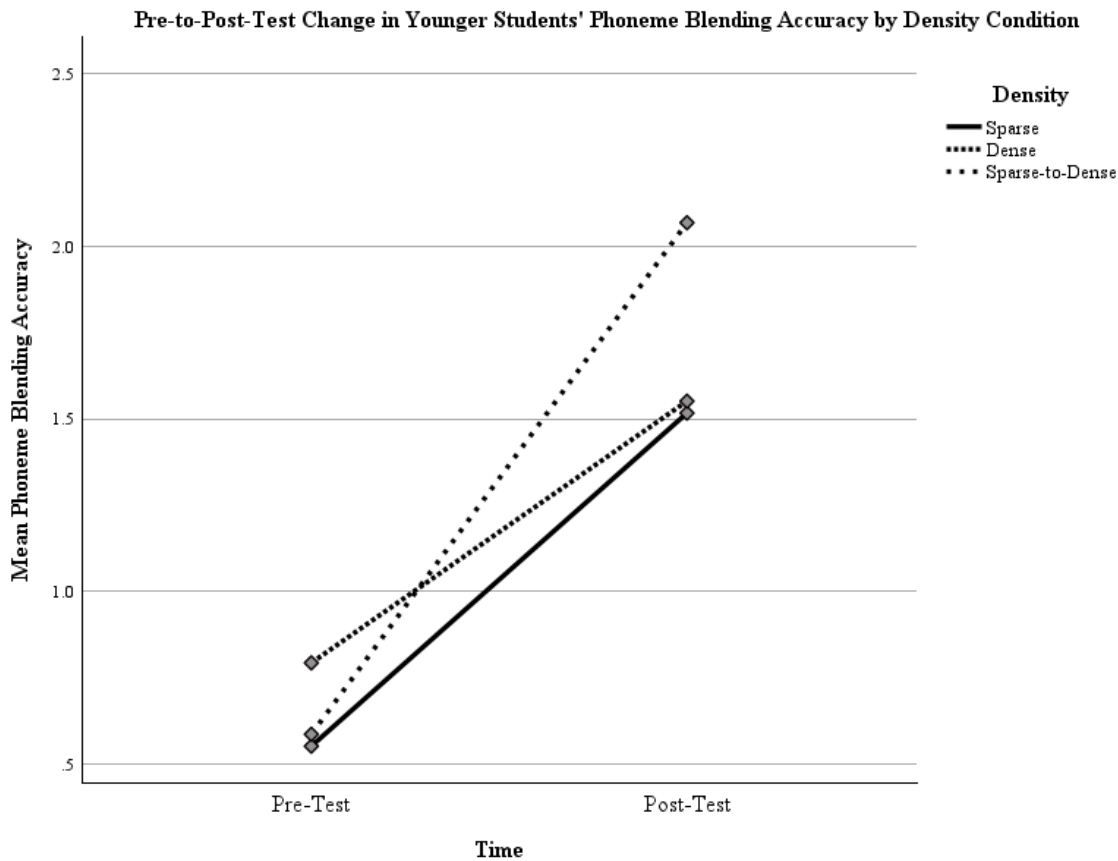
To explore the interaction, simple effects analyses (one-way ANOVAs) were conducted at pre-test and post-test (see Figure 3). Phoneme blending accuracy was not significantly different between the density conditions at pre-test $F(2, 56) = 1.566, p = .218, \eta_p^2 = 0.053$. However, significant differences in phoneme blending accuracy between the three density conditions were detected at post-test $F(2, 56) = 3.489, p = .037, \eta_p^2 = 0.111$. Pairwise comparisons revealed that post-test blending accuracy in the sparse-to-dense condition ($M = 2.069, SE = .424$) was significantly higher than in the sparse condition ($M = 1.517, SE = .316$) and the dense condition ($M = 1.552, SE = .380$). Overall, younger children showed greater gains in phoneme blending accuracy for nonwords that had phonological neighbors introduced during the intervening task, and this was associated with a medium effect size.

Research Question 2: Supplementary Analysis

Approximately one-third of the younger group (10 of 29) were unable to blend any items at pre-test or post-test; I therefore ran this analysis again including only those younger children who displayed some level of emerging phonemic awareness (i.e., who blended one item or more accurately at pre-test or post-test; $n = 19$). This supplementary analysis was conducted to evaluate the robustness of the interaction by minimizing potential floor effects and the associated increases in error variance and the skewness of these variables for this young group. Thus, this

Figure 3.

Pre-to-Post Change in the Younger Groups' Phoneme Blending Accuracy by Density Condition.



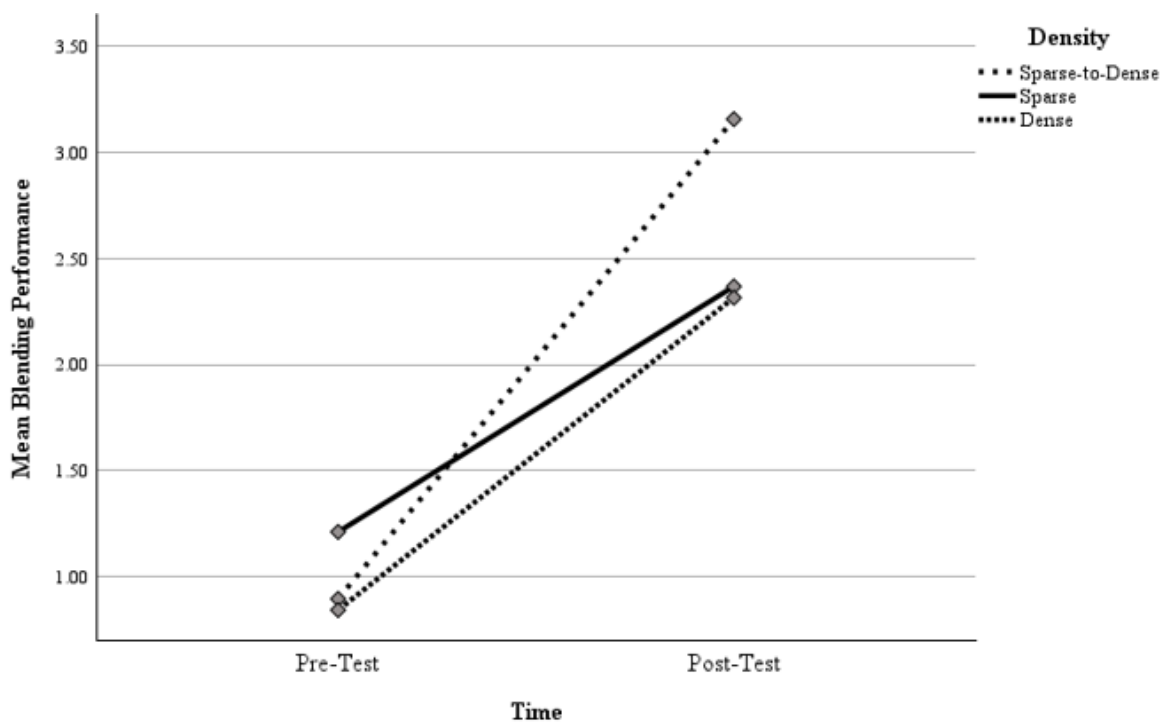
re-analysis addressed these normality concerns as all skewness and kurtosis values for this subset of younger students were within acceptable ranges (Hair et al., 2010). Mauchly's test indicated that the assumption of sphericity was met for the interaction term $\chi^2(2) = .189, p = 0.910$. Results showed a significant main effect of time $F(1, 18) = 48.259, p < .001, \eta_p^2 = 0.728$ and a significant Time x Density interaction $F(2, 36) = 4.783, p = .014, \eta_p^2 = 0.210$, indicating that the amount of improvement from pre-to-post-test differed depending on the density condition.

To examine the interaction, separate one-way ANOVAs were performed at pre-test and post-test. Phoneme blending performance at pre-test was not significantly different between the density conditions, $F(2, 36) = 1.583, p = .219, \eta_p^2 = .081$. However, significant differences in

phoneme blending accuracy were detected between the conditions at post-test $F(2, 36) = 3.664, p = .036, \eta_p^2 = .169$. Pairwise comparisons revealed that nonwords in the sparse-to-dense condition ($M = 3.158, SE = 0.485$) were blended more accurately than those in the sparse condition ($M = 2.316, SE = .367$) and the dense condition ($M = 2.368, SE = .485$); there were no differences between the sparse and dense conditions (see Figure 4). Overall, the pattern of results for this subset of younger children with some phonemic awareness was the same as that found for the entire younger group; that is, they showed greater gains in phoneme blending for nonwords that had phonological neighbors introduced in the intervening task, and this was associated with a large effect size.

Figure 4.

Pre-to-Post Change in the Phonemically Aware Younger Groups' Blending Accuracy by Density Condition.

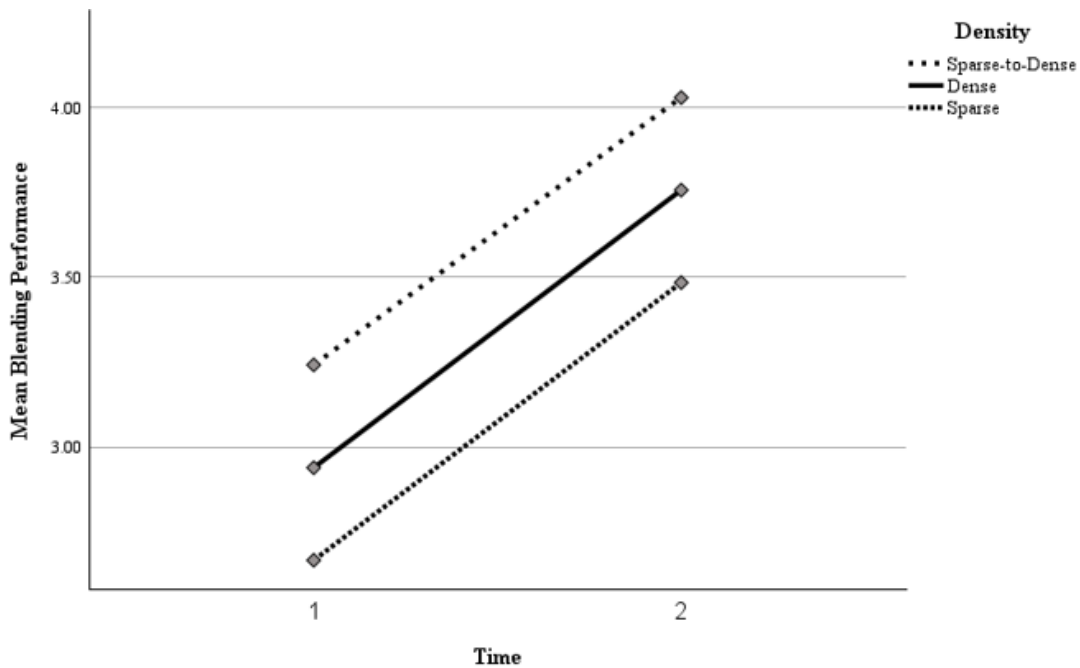


To examine the effects of neighborhood density on phoneme blending accuracy in the older group of students, the same two-way repeated measures ANOVA was performed.

Mauchly's test indicated that the assumption of sphericity was met for the density term $\chi^2(2) = 2.979, p = .226$. Results revealed statistically significant main effects of time $F(1, 32) = 12.312, p < .001, \eta_p^2 = .278$ and density $F(2, 64) = 6.430, p = .003, \eta_p^2 = .167$; there was no Time x Density interaction $F(2, 64) = .008, p = .992$.

The main effect of time indicated that phoneme blending accuracy significantly increased from pre-test ($M = 2.95, SE = 0.306$) to post-test ($M = 3.76, SE = 0.309$). Pairwise comparisons used to explore the main effect of density showed that phoneme blending accuracy in the sparse-to-dense condition ($M = 3.636, SE = .285$) was significantly higher than in the sparse condition ($M = 3.076, SE = .316$) and then in the dense condition ($M = 3.348, SE = .295$); there was no difference between the sparse and dense conditions (see Figure 5). Overall, the older children's phonemic awareness scores increased from pre-test to post-test and were better at both time points for the sparse to dense condition in comparison to the sparse and dense conditions.

Figure 5.
Pre-to-Post Change in Older Groups' Phoneme Blending Accuracy by Density Condition.



Research Question 3: Does repetition of nonwords from sparse neighborhoods account for unique variance in word learning?

Zero-order correlations amongst the variables examined in the subsequent regression analyses are presented in Table 2. As expected, measures of word reading and phonological awareness on both the CTOPP-2 and the experimental blending tasks were all significantly correlated. Nonword repetition was also significantly correlated with all phonological awareness and word reading measures, but did not correlate with immediate recognition on the word learning task. The word learning task was only correlated with pre-test phoneme blending accuracy for sparse items.

Table 2.

Correlations amongst the variables used in regressions 1, 2, and 2b.

Variable	1.	2.	3.	4.	5.	6.	7.
1. Grade	-						
2. NWR Dense	0.354**	-					
3. NWR Sparse	0.256	0.766***	-				
4. WL Total Score	-0.033	0.044	0.265	-			
5. Pre-PA Dense	0.537***	0.475***	0.451***	0.180	-		
6. Pre-PA Sparse	0.538***	0.486***	0.481***	0.326*	0.826***	-	
7. CTOPP-2 Elision	0.263*	0.482***	0.506***	0.096	0.371**	0.483***	-
8. Word ID	0.679***	0.388**	0.415**	0.136	0.610***	0.737***	0.574***

Notes. NWR = nonword repetition; WL = word learning; Pre-PA = pre-test phonemic awareness; CTOPP-2 Elision = Comprehensive Test of Phonological Processing – Second Edition elision subtest; Word ID = Word Identification subtest (Woodcock Reading Mastery Tests – Third Edition).

* $p < .05$, ** $p < .01$, *** $p < .001$

To address whether the repetition of nonwords from sparse neighborhoods accounted for unique variance in word learning, a hierarchical regression was conducted on children’s mean accuracy across the 18 nonwords taught in the word learning training. Grade and nonword repetition for dense items were entered as controls in Steps 1 and Step 2, accounting for a nonsignificant 0.4% of the variance in word learning. In Step 3, nonword repetition accuracy for sparse nonwords accounted for an additional and statistically significant 13.1% of the variance in word learning (see Table 3). Although the zero-order correlation between nonword repetition of

sparse syllables and word learning was nonsignificant, a partial correlation controlling for grade indicated a significant positive association, $r(49) = .282, p = .045$.

Research Question 4: Does phonemic awareness for sparse nonwords predict unique variance in word reading beyond that accounted for by grade, phonemic awareness performance for dense nonword items, and general phonological awareness?

Table 3.
Hierarchical regression predicting word learning recognition performance (n = 52).

Step	Predictor	ΔR^2	Initial β [95% CI]	Final β [95% CI]
1	Grade	.001	-.027 [-.317 - .262]	-.039 [-.334 - .254]
2	Nonword Repetition Dense	.003	-.061 [-.236 - .352]	-.377 [-.782 - .056]
3	Nonword Repetition Sparse	.131**		.566** [.137 - .945]

Notes. Standardized beta coefficients (β) are reported. Because all variables were standardized prior to analysis, the reported confidence intervals for the unstandardized coefficients closely approximate those for the standardized betas.

* $p < .05$, ** $p \leq .01$ and *** $p < .001$.

This final analysis explored whether the pre-test phoneme blending accuracy on items from sparse neighborhoods accounted for unique variance in a standardized measure of word reading (i.e., the Word ID subtest from the WRMT-III). Grade was entered as the first step in a hierarchical regression and accounted for 46% of the variance. In Step 2, phoneme blending for dense nonwords accounted for an additional 8.5% of the variance. In Step 3, phoneme blending for sparse nonwords accounted for an additional 11.4% of variance. In the final step, the CTOPP-2 elision measure accounted for an additional 6% of the variance. In the final equation, grade, CTOPP-2 elision and phoneme blending for sparse nonwords were significant predictors of word reading. Overall, the final model explained 72% of the variance in word reading, and blending for sparse nonwords predicted unique variance even with this stringent set of controls (see Table 4).

Table 4.*Hierarchical regression predicting word reading performance (n = 62).*

Step	Predictor	ΔR^2	Initial β [95% CI]	Final β [95% CI]
1	Grade	.461***	.679*** [.490 - .869]	.408*** [.238 - .578]
2	Phoneme blending dense	.085*	.345** [.137 - .553]	-.089 [-.344 - .165]
3	Phoneme blending sparse	.114***	.610*** [.333 - .888]	.456** [.187 - .726]
4	CTOPP-2 elision	.060***		.279*** [.118 - .440]

Notes. Standardized beta coefficients (β) are reported. Because all variables were standardized prior to analysis, the reported confidence intervals for the unstandardized coefficients closely approximate those for the standardized betas.

* $p < .05$, ** $p \leq .01$ and *** $p < .001$.

Discussion

The lexical restructuring model makes specific predictions concerning the causal role of vocabulary growth, particularly learning more phonologically similar words (dense areas of children's lexicons), in the development of implicit and explicit phonological processing (Metsala & Walley, 1998; see also, Storkel, 2002). Although correlational research has largely supported the model, there has been less experimental research to test these causal claims more rigorously. The goals of this study were to test several of these claims as they relate to individual differences in word learning and phonemic awareness and their association with lexical restructuring. Furthermore, this study examined associations between the processing of sparse items with word learning and word reading. I next explore the major findings of this study for each research question.

This study examined the proposed relationship between neighborhood density and word learning. Theories have generally held that words from dense neighborhoods have more robust lexical representations than words from sparse neighborhoods because they must be stored and discriminated from many phonologically similar words in the listener's lexicon. In this manner,

learning and storing new words that need to be distinguished from many phonological neighbors should make it necessary to encode greater phonemic detail than for words with few similarly sounding word neighbors (e.g., Adlof & Patten, 2017; Storkel, 2004; see also Jusczyk et al., 1994). Furthermore, the new representations of a word and connections within the lexicon should become strengthened through repeated exposures to the newly learned word (Gupta & MacWhinney, 1997). Past research has found support for these claims. There is an advantage for learning words residing in dense neighborhoods in comparison to sparse neighborhoods, and this learning advantage appears to remain relatively stable across development (e.g., Hoover et al., 2010; Storkel et al., 2013; Storkel et al., 2006).

It was therefore hypothesized that dense nonwords would be learned more accurately than sparse nonwords; furthermore, I predicted that experimentally introducing nonword neighbors for a subset of the sparse nonwords would result in better learning performance compared to nonwords that remained in sparse neighborhoods. The introduction of phonological neighbors was expected to force students' attention to the internal phonological structure of the sparse nonwords, resulting in more robust lexical representations, and thus facilitate better performance on the word learning tasks. This sought to mimic what might be a mechanism of learning words in dense neighborhoods. The magnitude of the advantage for learning dense nonwords was also expected to be greater in the younger group than in the older group (see Storkel & Hoover, 2011). This is because older students know more words overall and have relatively more words in sparse neighborhoods than younger students. Contrary to expectations, however, results showed that sparse nonwords were recognized more accurately than nonwords in the dense condition and in the sparse-to-dense condition for both age groups. It should be noted, however, that the word learning task used in this study was challenging for the

participants in each group, with relatively few words learned overall. As such, the results should be interpreted as preliminary, and future research should further investigate these findings using tasks that may be more accessible for young children.

While this result was not hypothesized, it is not fully inconsistent with some past findings and theoretical positions. Storkel and colleagues (2011; 2006) have proposed differing effects of neighborhood density in different phases of word learning. In the initial stages, when a novel word is encountered, no exact match exists in long-term memory, and this mismatch is thought to trigger the learning process (Li et al., 2004; Storkel & Lee, 2011). Importantly, the degree of mismatch is proposed to influence the strength of the signal to construct a new lexical representation. For words with few similarly sounding words in the listener's lexicon (i.e., those residing in sparse neighborhoods), novel words share fewer overlapping phonological segments with known words, and the mismatch is relatively large. This makes it more likely that the input will be detected as novel and initiate the formation of a new representation (Li et al., 2004). In contrast, dense nonwords share many overlapping segments with existing words, which may increase the risk of retrieval errors and interference from phonologically similar representations. As a result, dense nonwords may be less likely to initiate the learning process as quickly and more prone to confusion with known words (Storkel & Adlof, 2009; Storkel & Lee, 2011; Storkel et al., 2006). An implication of this may be reduced accuracy for dense words in comparison to sparse words when learning is assessed immediately following brief training procedures. For example, Storkel & Lee (2011) found that four-year-old children showed higher learning performance for sparse nonwords than dense nonwords immediately following training on a referent identification task — a task similar to that used in current study. However, they also found that learning performance for dense nonwords, but not sparse nonwords, improved

following a one-week delay. Furthermore, Storkel et al. (2006) found that adults formed more complete representations for high-density nonwords following multiple nonword exposures, but showed similar learning performance for high-density and low-density nonwords after fewer exposures; they concluded that "...neighborhood density may be less critical in the earliest stages of word learning." These findings align with proposals that word learning may be a protracted process, during which the integration of a new word representation with existing ones occurs separately from the initial creation of the representation (Gaskell & Dumay, 2003; Leach & Samuel, 2007).

In terms of the current study, the recognition task occurred immediately after the word learning training. Moreover, learning performance across density conditions was quite low in each group of students, demonstrating that learning of these nonwords did not necessarily progress past the initial phase of word learning when the strength of the triggering signal may be most influential. Introducing the nonword neighbors immediately before a sparse-to-dense item was taught may have also led to increased confusability among these items during the recognition task. Thus, the current study appears to have measured this initial triggering phase of word learning, rather than the later stages of this process when the effects of increasing word neighborhood density are expected to better support word representations. Future studies could examine the experimental effects of neighborhood density on word learning with a task that covers the phases of learning more extensively. Furthermore, our word learning task appeared too difficult for children and might be enhanced by more frequent exposures of the nonwords and fewer nonwords introduced in one setting (e.g., Storkel et al., 2011; see also Gupta & MacWhinney, 1997).

A second goal of this study was to examine the effects of lexical neighborhood density on

phonemic awareness; specifically, how phoneme blending accuracy was impacted from pre-test to post-test when phonological neighbors were introduced. A central proposal made by the lexical restructuring model is that segmental restructuring is a protracted process linked to multifaceted vocabulary growth, including global factors (e.g., vocabulary breadth) and local factors (e.g., neighborhood density); explicit processing is also proposed to be more sensitive to local factors earlier in development (Metsala, 2011a; Metsala & Walley, 1998). In support of these theoretical claims, past correlational research has reported advantages for words from dense neighborhoods on phonological awareness tasks in young children (e.g., Goswami & DeCara, 2000, 2003; Hogan et al., 2011; Metsala, 1999). As well, performance on explicit tasks appears to become less tied to neighborhood density later in development (e.g., Hogan et al., 2011; Metsala, 2011a).

Accordingly, I predicted that phonemic awareness performance would improve the most from pre- to post-test for words in the sparse-to-dense condition. I also expected this effect to be more prominent in the younger group of students. The analysis showed that younger students' phoneme blending accuracy was not significantly different across the three neighborhood density conditions at pre-test, but performance in the sparse-to-dense condition was significantly higher at post-test. This finding was robust, as the same interaction effect emerged when the analysis was repeated to include only those younger children with some basic level of emerging phonemic awareness. Within the context of the claims made by the lexical restructuring model, this finding supports the interpretation that increasing the number of phonologically similar neighbors prompted greater attention to the internal phonemic structure of the nonwords, increasing conscious access to this structure for use in the phoneme blending task at post-test.

This novel finding provides direct evidence for the causal claim that increasing

neighborhood density leads to improvements in access to the phonological representations of words — that is, to improved phonemic awareness. To my knowledge, there is only sparse research that has experimentally manipulated neighborhood density to examine its effects on explicit phonemic processing. This finding aligns with and extends the longitudinal findings reported by Lonigan (2007). In that study, a vocabulary intervention produced significant improvements in preschoolers' phonological awareness from pre-test to post-test; however, the specific role of neighborhood density was not examined. It also expands upon the results of past experimental studies reporting findings similar to Lonigan (2007), but who either did not fully isolate the effects of vocabulary knowledge on phonological awareness development (e.g., Duff et al., 2017; Porta & Ramirez, 2020) or find evidence of a converse relationship (i.e., that phonological awareness interventions did not improve vocabulary knowledge; see O'Leary, 2017).

On the other hand, older students did not perform as predicted; in comparison to the sparse and dense nonwords, this group demonstrated stronger blending performance on the sparse-to-dense nonwords at both pre- and post-test. One possible explanation for this finding may be related to developmental changes in the structure of the lexicon. As children's vocabulary knowledge increases, phonological similarity relations among lexical items are also proposed to increase, thereby making neighborhood density more equivalent across different lexical neighborhoods (Storkel, 2004). Consequently, the older students in this study may have been further along in that most words in their lexicon were already segmentally represented. This potentially greater neighborhood density equivalence in the older group could have resulted in phonemic awareness performance that was mostly independent of long-term lexical knowledge and therefore minimized the impact of experimentally introducing the phonological neighbors.

Other differences in group characteristics may also explain why the interaction effect was found in the younger group, but not the older group. First, the younger group consisted solely of students in Grade Primary, and data was collected between November and March of the school year. Therefore, this younger group would have received relatively less direct instruction in explicit processing tasks (e.g., phonemic awareness and learning to read words) than the students in first and second grade. Therefore, phonemic awareness in the younger group of students may have been more tied to lexical characteristics, while explicit processing in the older group may have been more independent of these factors. This interpretation aligns with previous work suggesting that neighborhood density plays a more influential role in explicit phonological processing tasks earlier in development, and diminishes as children increase their vocabulary knowledge and receive direct instruction and practice in accessing and manipulating phonemes (e.g., Metsala, 1999; Hogan et al., 2011). For example, Hogan et al.'s (2011) longitudinal study found that students deleted phonemes from dense items more accurately than sparse items in second grade, but this neighborhood density advantage decreased in fourth grade. However, the older group in the current study was comprised of students in first and second grade, and introduction of neighbors did not produce a steeper slope of improvement relative to the sparse and dense conditions. Future research might clarify these inconsistencies by more closely examining developmental trajectories in relation to the association between lexical characteristics and explicit phonological processing tasks.

The third goal of this study was to examine whether the repetition of sparse nonwords contributed to children's performance on the word learning task. Of interest to the current study was the position that individual differences in nonword repetition tasks are due to vocabulary knowledge and index the quality or structure of underlying lexical representations (Bowey, 2001;

Dollaghan et al., 1995; Metsala, 1999; Metsala & Chisholm, 2010; Snowling et al., 1991; for a review, see Coady & Evans, 2008). Another argument stemming from this position is that individual differences in the capacity to repeat nonwords from sparse neighborhoods may be a particularly sensitive indicator of the extent to which lexical representations are fully phonemic throughout the lexicon (Metsala, 2011b; Munson et al., 2005; see also Walley et al., 2003). As previously reviewed, phonemically organized representations in the existing lexicon have been theorized to facilitate word learning performance (e.g., Adlof & Patten, 2017; Storkel, 2004). Furthermore, nonword repetition may be expected to be a particularly strong predictor of word learning given that a reciprocal relationship has been found between these two constructs (Bowey, 2006; Gathercole, 2006).

In accordance with my prediction, the repetition of sparse nonwords explained unique variance in word learning beyond that accounted for by grade and the repetition of dense nonwords, neither of which accounted for a statistically significant portion of the variance. This is a novel finding, given that relatively few studies have examined the role of neighborhood density in nonword repetition tasks, and to my knowledge, none have examined how the repetition of nonwords from sparse and dense neighborhoods contributes to spoken word learning. This finding also lends support to conclusions from some previous research that has reported associations between individual differences in lexical refinement and more explicit processing tasks. For example, Metsala's (2011b) longitudinal study of Grade 1 children found that repetition of nonwords low in wordlikeness accounted for unique variance in both concurrent phonological awareness and later word reading ability, whereas repetition of nonwords high in wordlikeness did not. The current finding of a unique contribution from the repetition of nonwords with sparse syllables, therefore, adds to the small body of evidence which

has shown that individual differences in lexical refinement are associated with tasks which primarily depend on explicit phonological processing.

There are some limitations to note concerning this analysis. First, the zero-order correlations between nonword repetition accuracy in the sparse and dense conditions and the word learning task were not statistically significant. This may be at odds with past research reporting strong relationships between nonword repetition (albeit without reported measures of neighborhood density) and word learning in both children and adults (e.g., Gathercole et al., 1997; Gupta, 2003). As previously discussed, the word learning task in the current study may have best captured the initial stages of the word learning process, perhaps limiting the association with nonword repetition more generally. Additionally, nonword repetition for sparse items was significantly correlated with word learning when the effects of grade were controlled for, indicating that grade may have been suppressing this relationship. Another limitation is that grade also did not predict significant variance in word learning. Grade was expected to be a significant predictor because older students routinely perform better on these and related tasks due to more segmentally organized lexicons, and because segmental processing is proposed to become less constrained by lexical characteristics later in development – that is, the high-density advantage for nonword repetition and word learning may diminish as age-related increases in vocabulary growth lead to more equivalency in neighborhood density across words. Supporting this view, Storkel & Hoover (2011) found that children higher in expressive vocabulary learned nonwords with sparse vowel-consonant clusters more effectively than children lower in expressive vocabulary. A final limitation in the word learning task, as previously discussed, may have been that the task was too difficult to adequately measure word learning, perhaps even

variation in the initial stages of such. Nonetheless, nonword repetition for sparse nonwords was uniquely predictive of word learning, consistent with the hypothesis based on past research.

The final aim of this study was to explore whether there were unique contributions of phonemic awareness for nonwords with few neighbors to children's word reading. Phonemic awareness is an important skill for developing decoding or word reading skills (e.g., Metsala et al., 2009; Wagner & Torgesen, 1987). Given that word reading is highly dependent on this ability to consciously access and manipulate phonemes, the segmental restructuring of lexical representations has been theorized to be an important contributor to literacy development (Walley et al., 2003; see also Brady & Shankweiler, 1991). As previously discussed, phonemic awareness for nonwords with few similarly sounding neighbors has been proposed to index the level of refinement in lexical representations. I therefore predicted that phonemic awareness performance for sparse nonwords would explain unique variance in word reading beyond the effects of those for dense nonwords, and a measure of general phonological awareness. As demonstrated in the final regression analyses, phoneme blending for nonwords with few similarly sounding words in the listener's lexicon accounted for unique variance in word reading beyond that accounted for by grade, phonemic blending for nonwords with many similarly sounding neighbors, and even a robust standardized measure of phonological awareness. Overall, these results are strong evidence for the robust association between phoneme awareness for sparse stimuli as a predictor of word reading during the early elementary school years.

This finding adds to past research supporting the claim that task performance on stimuli from sparse neighborhoods indexes lexical refinement. For example, Metsala (1997) found that in children approximately seven years old, recognition of spoken words from sparse neighborhoods, alongside phonemic awareness, predicted unique variance in both word and

pseudoword reading; recognition of words in dense neighborhoods did not show this association. Garlock et. al (2001; see also Metsala et al., 2009) reported that preschoolers' and kindergarteners' performance on speech recognition tasks for words from sparse neighborhoods predicted concurrent phonological awareness and was indirectly related to word reading ability; again, this association was not found for speech recognition tasks with words from dense neighborhoods. While these past studies were focused on implicit speech processing tasks, this finding in the current study highlights that the effects of neighborhood density are also generalized to explicit phonological processing tasks — namely, phonemic awareness. While the relationship between phonemic awareness and word reading is robust overall, the current finding also demonstrates that this association varies as a function of neighborhood density. Thus, individual differences in the ability to explicitly process items from sparse neighborhoods (which is suggested to measure how far along overall segmental representation is for a listener) is uniquely associated with developing word reading skills.

Implications and Limitations

The major aim of this study was to test several causal claims made by the lexical restructuring model through experimental manipulations designed to mimic the effects of building dense neighborhoods. A further goal was to examine associations with the processing of stimuli varying in neighborhood density. The results discussed here have implications primarily for theory, although they are suggestive of some applied research to further examine potential practical implications. The findings provide support for the causal claims made by the lexical restructuring model by showing that the experimental increases in phonological similarity simulated lexical restructuring, or at least attention to phonemic detail for young children, thereby facilitating their explicit processing at the level of the phoneme. Additionally,

performance on items from sparse neighborhoods showed unique associations with word learning and word reading, suggesting that the ability to access and manipulate such sound sequences is an effective probe of the level of refinement overall in a listener's lexical representations. That is, these findings support the theoretical claim of the importance of vocabulary growth (in terms of increasing lexical neighborhood density) on explicit phonological processing, or a listener's access to the phoneme on these tasks. The finding that the influence of neighborhood density on phonemic awareness tasks may vary with age and exposure to formal reading instruction also offers further theoretical support for the model, as evidenced by the different pattern of results found in each group of students. This aligns with and supports theoretical claims that phonemic processing/organization gradually becomes more independent of lexical characteristics as children's representations mature (Metsala, 2011a; Metsala, 1999; Metsala & Walley, 1998). A final theoretical implication extends to word learning. Although increased neighborhood density should play a facilitative role in learning new words via more connections to existing representations, the findings of this study suggest that during the earliest phase of learning, items from sparse neighborhoods may be more effective triggers to encode a new word in lexical memory. This supports proposals that lexical similarity may initially inhibit this triggering phase and only facilitate the encoding of words and more refined representations during the stages that follow, or after more repeated exposures to the stimuli have occurred (e.g., Storkel & Lee, 2011; Storkel et al., 2006).

These findings may inform further research on how these theoretically supported claims might be applicable for the early identification of reading difficulties in children. While examinations of such were beyond the scope of this study, one suggestion is that stimuli from sparse neighborhoods could be incorporated into early literacy screening measures as indicators

of potential delays in segmental representation of spoken words; this has been proposed to be a deficit in children with reading disabilities (e.g., Brady, 2020; Brown, 1997; Metsala, 1997). That is, performance on words from sparse neighborhoods may be more sensitive to early difficulties in implicit and then explicit processes that are necessary for typical literacy development.

There are also limitations to the current study, as with all research, that should be considered when interpreting the conclusions. One limitation is that data collection was interrupted by the COVID-19 pandemic and the subsequent province-wide shutdown of all public schools in Nova Scotia. This resulted in a final sample that was smaller than initially planned. With these sample sizes, it was determined best to analyze results for the younger and older groups separately, rather than to make developmental comparisons more directly. Thus, replication of these results with a larger sample size and direct comparisons of developmental differences is needed. As previously discussed, another limitation is that the word learning task in the current study proved to be quite difficult for the students, and thus may not have allowed for more robust learning of the stimuli. As such, the learning that did occur may have only captured very initial stages of word learning. It may be that introducing fewer word items and using tasks such as interactive games or storybooks allow for learning to occur on a deeper level, as has been reported in other studies (e.g., Storkel et al., 2013; Storkel & Hoover, 2011; Storkel & Maekawa, 2005). As with any research, there is a balance between including enough items to allow for meaningful comparisons across conditions and avoiding so many that the task becomes overly difficult. A final limitation to consider is that while conclusions concerning causal claims can be drawn regarding the effects of neighborhood density on phonemic awareness gains and word learning, other results remain within a correlational framework and require further experimental manipulations to help establish robust evidence. Nonetheless, the correlational

findings in this study do provide insight into how words that vary in the number of lexical neighbors relate to word learning and word reading.

Conclusion

In summary, this study used experimental manipulations of neighborhood density to test several causal claims of the lexical restructuring model related to individual differences in skills linked to lexical restructuring – specifically, the role of neighborhood density in early elementary school children’s phonemic awareness and word learning task performance. Introducing phonological neighbors to transition words from residing in sparse neighborhoods to dense neighborhoods did not result in improved word learning performance in either group; however, it did produce significant changes in phonemic awareness in the younger group of students, whose phonemic processing may still be dependent on lexical characteristics. This study also examined associations between segmental representation and word learning and word reading. It was found that processing stimuli from sparse neighborhoods was a significant predictor of unique variance in each, suggesting that the ability to process such items may be a sensitive indicator of the overall refinement of lexical representations. Continued research using similar experimental approaches will be important to further clarify how phonological processing contributes to early literacy development.

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Appendix A

The nonword-nonobject stimuli used.

Day 1 items:

1. Roosh (Sparse)
2. Feeg (Sparse-to-Dense)
3. Yed (Dense)
4. Soag (Sparse)
5. Rouch (Sparse-to-Dense)
6. Bape (Dense)
7. Gooj (Sparse)
8. Doit (Sparse-to-Dense)
9. Fide (Dense)

Day 2 items:

10. Bown (Dense)
11. Looch (Sparse-to-Dense)
12. Yib (Sparse)
13. Liss (Dense)
14. Wube (Sparse-to-Dense)
15. Boip (Sparse)
16. Seef (Dense)
17. Deej (Sparse-to-Dense)
18. Fowsh (Sparse)



1 - roosh



2 - feeg



3 - yed



4 - soag



5 - rouch



6 - bape



7 - gooj



8 - doit



9 - fide



10 - bown



11 - looch



12 - yib



13 - liss



14 - wube



15 - boip



16 - seef



17 - deej



18 - fowsh

Appendix B

Neighborhood density means and standard deviations for the 3 categories of nonwords based on the child corpora and the adult corpora.

	Adult Neighborhood Density			Child Neighborhood Density		
<i>ND</i>	Sparse	Dense	Sparse-to-Dense	Sparse	Dense	Sparse-to-Dense
<i>M</i>	6.33	19.83	7.5	3.50	14.17	4.00
<i>SD</i>	3.72	3.34	4.09	1.51	2.22	2.00

Note. *ND* = neighborhood density. *M* = mean. *SD* = standard deviation.