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A beautiful day in the neighborhood:
The influence of neighborhood density on speech production

A dissertation submitted in partial satisfaction of the
requirements for the degree Doctor of Philosophy

in

Language and Communicative Disorders

by

Skott Elliot Freedman

Committee in charge:

University of California, San Diego

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Professor Jessica Barlow, Chair
Professor Sonja Pruitt

2009

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Chair

University of California, San Diego

San Diego State University

2009

DEDICATION

For my family, on both coasts

EPIGRAPH

Be patient toward all that is unsolved in your heart
and try to love the questions themselves.

Rainer Maria Rilke

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LIST OF ABBREVIATIONS

ND neighborhood density
PP..... phonotactic probability
WFI.....word-finding impairment
PPVT Peabody Picture Vocabulary Test
PMLU.....phonological mean length of utterance
PWPproportion of whole-word proximity
PI.....phonological impairment

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ABSTRACT OF THE DISSERTATION

A beautiful day in the neighborhood:
The influence of neighborhood density on speech production

by

Skott Elliot Freedman

Doctor of Philosophy in Language and Communicative Disorders

University of California, San Diego, 2009
San Diego State University, 2009

Professor Jessica Barlow, Chair

The goal of the current work was to investigate the influence of neighborhood density (ND) on speech production. ND is an index of phonological similarity and refers to the number of meaningful words (neighbors) present in a language that differ

only by adding, deleting, or substituting a phoneme in any word position (Vitevitch & Luce, 1998, 1999). Prior studies of ND have yielded conflicting findings for production, reporting both inhibitory and facilitory effects of ND (Heisler, 2004; Vitevitch, 2002). In order to discern whether words may act more as competitors or facilitators (or potentially neither) during speech production, three experiments were conducted with 39 preschoolers and 46 adults with typical development: Experiment 1 explored influences of ND during children's picture-naming, Experiment 2 considered effects of ND on adult word repetition, and Experiment 3 discerned the influence of ND during word learning in both age groups. Analyses of production included segmental and whole-word level errors, as well as the lexical nature of production errors.

Results revealed varying effects of ND depending upon the task and group. Specifically, children's naming was facilitated by ND at the semantic level, yet unaffected by ND at the phonological level. Adult word repetition was facilitated by ND in terms of repetition accuracy and the nature of erred repetitions. Finally, an inhibitory effect of ND was found during word learning by children, while adults were seemingly unaffected by the ND manipulation during word learning.

Taken together, the results suggest that words do not simply act as competitors or facilitators during speech production; rather, their interactive nature likely depends on the elements of a task and the developing status of the lexicon. Neighbors of a word appeared to generally act as facilitators until a threat was posed, such as when acquiring novel words that were similar in phonological composition to existing words in the lexicon. This research indicates that incorporating ND into experimental or

treatment paradigms should be used with caution and should be based on the demands of a task as well as the participants involved.

CHAPTER 1

Background and literature review

INTRODUCTION

At first glance, lexical acquisition can seem like an incredibly daunting task. Environmental input presented at a fairly rapid rate must be mapped onto detailed linguistic representations. Specifically, a word's corresponding semantic properties, phonological segments, and syntactic functions must all be extracted from the incoming speech stream. Surprisingly, this potentially arduous task is typically executed with little effort by children barely a year of age. Moreover, phonological mapping of a novel word can occur with as little as one exposure, even in a naturalistic setting (Carey & Bartlett, 1978).

Several theories of lexical acquisition have been proposed to account for this observed ease of learning. One viewpoint attributes facilitated word learning to *co-occurrences* inherent in the input (Plunkett, 1997; Samuelson & Smith, 1998; Smith, 1995, 1999). For example, children are known to generalize labels of novel objects to other objects similar in shape, regardless of different functions (Jones, Smith, & Landau, 1991). An awareness of such regularities in the environment extends beyond semantics to syntactic, morphological, and phonological cues available in the input. These cues interact during development with other substrates of language, such as the lexicon. Our focus here is on the interaction between phonology and the lexicon.

Phonology and the lexicon. The notion that the lexicon significantly affects phonological development was proposed over 30 years ago by Ferguson and Farwell (1975), who argued that “a phonic core of remembered lexical items and the articulations that produced them is the foundation of an individual's phonology”

(p. 437). During phonological acquisition, children learn what sounds may occur, in what context, and in what order. Lexical acquisition is thereby facilitated by constraining permissible meaningful forms (Coady & Aslin, 2003). Even with a restricted number of possible phonological structures, though, thousands of potential sound combinations exist. Fortunately, phonological variables embedded in the input appear to assist children in acquiring words at a rapid rate. For instance, consider *phonotactic probability*, which refers to the probability of sounds occurring and co-occurring in a given language (Vitevitch, Luce, Charles-Luce, & Kemmerer, 1997; Vitevitch & Luce, 1998, 1999). Research findings regarding the effects of phonotactic probability on language use have been fairly consistent for both children and adults, with a high probability advantage found during repetition, naming, and word learning tasks (Munson, 2001; Storkel, 2001; Storkel & Rogers, 2000; Newman & German, 2005).

Investigations of related phonological factors, in contrast, have not been nearly as consistent. For example, studies on effects of *neighborhood density*, relating to the phonological similarity of words, have shown largely conflicting findings with differences occurring between ages, tasks, and domains (perception, production) (Heisler, 2004; Storkel, Armbruster, & Hogan, 2006; Newman & German, 2002, 2005; Vitevitch, 2002; Coady & Aslin, 2003). In this dissertation, we focus on neighborhood density in an attempt to gain a better understanding of its role in speech production by both children and adults and across a variety of tasks.

Dissertation layout. The organization of this dissertation will be structured as follows. First, the remainder of Chapter 1 will provide a review of the empirical research on neighborhood density on which the subsequent studies are set. Next, the influence of neighborhood density on speech production will be considered across several tasks in Chapters 2 through 4. Chapter 2 explores how neighborhood density may influence children's accuracy during picture naming, Chapter 3 examines effects of neighborhood density on adult word repetition during noise interference, and Chapter 4 investigates the relationship between neighborhood density and word learning by children and adults on the same task. The final Chapter 5 summarizes the experimental findings, draws appropriate conclusions, considers the theoretical and clinical implications of the findings, and suggests future areas of research that can offer clarification on unresolved issues.

1.0 NEIGHBORHOOD DENSITY

1.0.1 Defining phonological similarity. Neighborhood density (hereafter, ND) refers to the number of meaningful words, or *neighbors*, present in a given language by adding, substituting, or deleting a phoneme in any word position (Vitevitch & Luce, 1998, 1999). Previous studies have found that using this single-phoneme metric has psychological validity. For example, Luce and Large (2001) reported that when participants were presented with a nonword and asked to produce the closest real word, more than 70% of responses involved a one-phoneme change. Thus, speakers of a language appeared to share similar definitions of phonological

similarity. Consider the English word “cat” /kæt/. By substituting the first sound, the words “mat” /mæt/, “bat” /bæt/, “sat” /sæt/ (and so on) would be considered neighbors. Similarly, “at” /æt/ is a neighbor of “cat” by deleting the initial segment, as are “can” /kæn/ and “cap” /kæp/, by substituting the final sound. A word with many neighbors, such as the above example of “cat”, is said to reside in a *dense* neighborhood and have high ND. In contrast, the English word “sniff” /snɪf/, which has few neighbors (e.g., “stiff” /stɪf/, “snuff” /snʌf/), is considered to reside in a *sparse* neighborhood and have low ND.

Research focusing on ND has experienced a surge in the last decade, particularly in areas of phonological acquisition (Gierut, Morrisette, & Champion, 1999; Morrisette & Gierut, 2002), speech perception (Luce & Pisoni, 1998; Vitevitch & Luce, 1998, 1999), word learning (Storkel et al., 2006; Heisler, 2004; Storkel, 2004), and speech production (Newman & German, 2005; Vitevitch, 2002; Gordon & Dell, 2001). Consistent findings have emerged from the speech perception and phonological acquisition literature that words with high ND can inhibit perception in terms of decreased accuracy on perceptual identification tasks (Luce & Pisoni, 1998; Cluff & Luce, 1990; Goldinger, Luce, & Pisoni, 1989), as well as result in the least amount of productive sound change in phonological treatment (Gierut et al., 1999; Morrisette & Gierut, 2002). On the contrary, conflicting and often inconsistent results have been reported for the influence of ND on speech production. Some researchers have reported an advantage for words with low ND (low ND > high ND), and have assumed that words with high ND might inhibit production during naming due to

lexical competition with similarly-sounding forms (Newman & German, 2002, 2005). Yet, other researchers have described a more facilitative effect of ND (high ND > low ND), which has been argued to be due to increased levels of overall lexical activation (Vitevitch, 2002; Storkel et al., 2006). And finally, null effects of ND (low ND = high ND) have also been reported (Vitevitch, Armbruster, & Chu, 2004). In light of the confusion stemming from prior research, it is presently uncertain whether words may act competitively or facilitatively with one another (or neither) during the speech production process. Alternatively, differences related to stimuli, task, or age may be responsible for the inconsistencies observed across previous findings. The primary goal of the current work therefore was to narrow the existing gap in the literature surrounding how ND may influence speech production in children and adults.

1.0.2 Modeling ND. In addition to investigating effects of ND on production, another goal of the present research program was to better understand how the *organization* of the lexicon might cause such effects. Previous accounts of the interaction between phonology and the lexicon have typically been represented using connectionist models (Gupta & MacWhinney, 1997; Luce, Goldinger, Auer, & Vitevitch, 2000; see Storkel & Morrisette, 2002, for discussion). Connectionist frameworks presume that words, referred to as *nodes*, have activation states, and that connection weights exist between these nodes and their neighbors. Activation states and connection weights have often been invoked to explain increased production accuracy for certain types of words, such as those with high frequency. For example, Storkel and Morrisette (2002) presented a two-representational model incorporating

phonotactic probability (hereafter, PP) and ND, based on existing work (e.g., Gupta & MacWhinney, 1997; Luce et al., 2000). Briefly, a word has two representations in the model. One representation resides at the phonological level and corresponds to a word's individual sounds and sequences; PP is believed to operate here. The other representation lies at the lexical level and refers to a word as a whole unit; ND is purported to operate here. As a feature of the model, before a word can be produced, its representation must reach a critical level called the *activation threshold*. This threshold refers to the amount of accumulated activation necessary before a lexical representation enters conscious awareness. A speaker may then select the word to be produced to initiate motor planning stages.

Under this model, words with high ND may compete with one another during production if they become activated themselves, thereby delaying the activation threshold for a target item. At the same time, words with high ND might instead facilitate a target word by feeding activation via shared phonological segments. Given that activation has the possibility of being both facilitatory and inhibitory in the model, it is difficult to predict under which circumstances (and why) such activation would occur. Additionally, the model does not explain how the *organization* of the lexicon would lead to such possibilities. For instance, are words with high ND clustered together in a common area of lexical space, or are connection weights sufficiently established regardless of where two words exist in the lexicon? Lastly, although representations must also include information about a word's meaning and grammatical properties, only a word's phonological composition is given

consideration in the two-representational model (Gupta & MacWhinney, 1997; Luce et al., 2000). Consequently, comparisons with other aspects of similarity in the lexicon, such as semantics, are not possible. Such comparisons can shed light on whether aspects of the lexicon (e.g., degree of similarity) are governed by similar underlying principles. By using a model that is capable of defining parameters more generally, we can increase our understanding of the lexicon in a broader context to other real-world cognitive systems. Insight can then be gained into how a network such as the lexicon evolves over time, as well as what factors appear to affect it (e.g., phonological similarity).

1.0.3 Graph theory. In order to examine the possibility that non-connectionist approaches might more generally represent the lexicon in terms of ND, Vitevitch (2008) adopted *graph theory*. This theory derives from mathematics and has been typically used by computer scientists and physicists to examine the structure of *complex systems* (for review, see Albert and Barabási, 2002; Barabási, 2002). By definition, complex systems refer to a vast number of individual units interacting in a relatively simple manner (Vitevitch, 2008). One example of such a system is the World Wide Web, where a plethora of individual websites are linked to many others (Pastor-Satorras & Vespignani, 2004). Two key terms necessary for understanding graph theory are *nodes* and *links*. Similar to connectionist models, in graph theory, words are represented by nodes, and links are the relationships between two nodes (neighbors). For example, in the World Wide Web, each website is a node, and the

relationship between two websites is represented by links between those nodes (Gruenenfelder & Pisoni, 2009).

One of the main advantages of graph theory is the ability to compare complex systems with one another based on a number of measurements. Three of these factors will be considered in relation to the graph theoretical analysis of the lexicon. First, the *average path length* refers to the mean distance between every node in a system and every other node in the same system (Watts & Strogatz, 1998). Next, the *clustering coefficient* considers the extent to which nodes (words) that are connected to other nodes are also neighbors with one another. A clustering coefficient of 0 indicates that no neighbors of a node are connected to any other neighbors of that node, and a clustering coefficient of 1 implies that all neighbors of a node are connected to one another. If a clustering coefficient falls between 0 and 1, this indicates some neighbors of a node are also neighbors of one another (Watts & Strogatz, 1998). Finally, the *degree of assortative mixing* refers to the probability that highly connected nodes are connected to other nodes that are also highly connected (Newman, 2002; Newman & Park, 2003). In a network with *disassortative* mixing, nodes with many connections are typically connected to nodes with relatively few connections. In contrast, in a network with *positive* assortative mixing, nodes with many connections tend to associate with similarly connected nodes.

Under the assumption that entries in the lexicon are stored in lexical neighborhoods (Luce & Pisoni, 1998; Storkel & Morrisette, 2002), Vitevitch (2008) visually graphed approximately 20,000 words from the 1964 *Merriam-Webster Pocket*

Dictionary according to ND. This same sample of words has been used extensively in previous studies of ND (e.g., Vitevitch & Luce, 2004, 2005; Nusbaum, Pisoni, & Davis, 1984), hence the relative age of the source. In the analysis, nodes were represented by words, and links were made between neighbors according to traditional definitions of ND (presented earlier). There were three major findings. First, results indicated that over 50% of lexical entries (n=10,265) are *hermits*, or words that have no neighbors (e.g., *spinach*), and are thus not connected to any other nodes. Second, a large number of small islands was found (n=2,567), where each node had only a few neighbors. And third, there was a single large island of over 6,500 words that had several links with one another. It was this larger island on which subsequent analyses (discussed below) were made.

As mentioned above, a key advantage of graph theory is the ability to compare various measurements of two complex systems with one another. Consider first the average path of length in a network. For the analysis of the lexicon, Vitevitch (2008) reported an average path length of 6.05. That is, approximately six links, on average, were necessary in order for one node to be connected to another. For instance, the word (node) “bat” /bæt/ can travel to the word “mud” /mʌd/ in three links: from “bat” to its neighbor “bad” /bæd/, from “bad” to its neighbor “mad” /mæd/, and finally to the target “mud”. (Note that the same is possible by traveling through “mat” /mæt/ and “mad” /mæd/.) The average path length of the lexicon, while slightly larger than a random network of comparison (with an average path length of 4), is comparable in graph theoretical analyses (Watts & Strogatz, 1998).

Considering next the extent to which words that are connected to other words are also neighbors of one another, Vitevitch (2008) found the clustering coefficient of the 20,000-word lexicon to be .126. This finding is indicative of a relationship between the neighbors of a word and one other. Namely, neighbors of a target word also tend to be neighbors of one another. Compared to the clustering coefficient of a random system (with a clustering coefficient of .001), the clustering coefficient of the lexicon is significantly higher (more than 90 times; Vitevitch, 2008).

Lastly, with respect to the relationship between words with similar NDs, Vitevitch (2008) discovered a positive degree of assortative mixing in the lexicon, indicating that words with many neighbors were also connected to words with many neighbors. Consequently, words with few connections were more connected to words with few connections. This finding is important for understanding potentially inhibitory effects of ND: Words with many neighbors could inhibit one another due to lexical competition. However, it seems as likely that such words could benefit from higher levels of activation compared to words with low ND, thus providing an advantage during production. As discussed above, connectionist models also predict both of these possibilities; yet, as will be shown, graph theory may be able to account for findings in the current work by incorporating aspects of the lexicon that are related to yet different from ND, such as the degree of assortative mixing.

Note that results of the analyses of the average path length and clustering coefficient together indicated that the lexicon has characteristics of a *small-world network* (Vitevitch, 2008; Watts & Strogatz, 1998). According to Watts and Strogatz

(1998), such networks have average path lengths that are comparable to random networks, yet higher clustering coefficients. Despite being very large and sparsely connected, network processing therefore can be rapid and accurate due to a relatively short number of connection paths and clusters. Vitevitch (2008) argues that this is an accurate description of language functioning because most functions are conducted in a quick fashion with high rates of accuracy. Furthermore, a small-world network has also been reported for other domains of language such as semantics. Steyvers and Tenenbaum (2005) reported that when the lexicon was graphed by semantic similarity (e.g., word associations, synonyms), it too was characterized by short average path lengths and strong local clustering.

In his discussion, Vitevitch (2008) proposed two central assumptions about the influence of ND based on the graph theoretical analysis. First, he advocated that due to a positive degree of assortative mixing, words in the lexicon likely benefit from activation spreading between neighbors. During naming, for example, if a word is not accessed correctly, a neighbor might be produced that is partially correct in accuracy. Vitevitch describes this process as one of “graceful degradation” as opposed to “catastrophic failure” that might be experienced in larger scale networks, where no item or, alternatively, an entirely different item is named.

The second assumption relates to the influence of ND on speech production. Since words with many neighbors have a greater number of connecting nodes, words with high ND could provide even *more* activation than those with low ND. This has been reported in prior research (Vitevitch & Sommers, 2003; Vitevitch, 2002).

Nevertheless, if such increased activation results in lexical competition, the opposite effect might be observed: Words with low ND would be produced more accurately than words with high ND (Newman & German, 2002, 2005).

Finally, Vitevitch (2008) proposed two mechanisms for word learning that might develop from a small-world network: *growth* and *preferential attachment*. Growth in a network refers to the addition of new nodes (words) over time. Given that both children and adults acquire new words throughout the lifespan, this mechanism seems compatible with the expansion of the lexicon. The second mechanism, preferential attachment, is a constraint that increases the likelihood of adding a new node to the system if it will connect to nodes that already have a high number of connections (Vitevitch, 2008). Under such a mechanism, words with high ND should be more easily acquired than those with low ND; this was found by Storkel et al. (2006), but is in direct contrast to findings of Heisler (2004). Specifically, Vitevitch (2008) theorized that uncommitted nodes—that is, empty nodes to which no semantic information is assigned—become partially activated by a novel auditory form, thereby storing that novel form’s phonological information. These nodes then compete with one another to become the final committed node that houses the newly acquired word. Only one node will ultimately assign itself to a word; still, the remaining partially activated nodes (with learned phonological patterns) stay available for incoming input. Thus, the next time a novel form is heard that is phonologically similar to these partially activated nodes, these nodes are the first in line to claim the form as their own.

1.0.4 Predictions of graph theory. Regarding how ND may influence speech production, graph theory makes two central predictions. First, words with high ND should be named and repeated more accurately than words with low ND. This is based on Vitevitch's (2008) observation that words in the lexicon likely benefit from activation spreading between one another due to a positive degree of assortative mixing. Thus, naming and repetition of words with many neighbors should be facilitated to a greater degree than words with only a few phonologically similar forms. Facilitated naming could result in increased production accuracy and less susceptibility to errors. Note, however, that this prediction is based on a typically functioning *adult* lexicon. It is therefore uncertain how developing networks, as with the case of children, may operate with respect to the influence of ND. Perhaps the size of a network would be relevant for how phonological similarity affects production. Additionally, although graph theory makes predictions based on naming accuracy at the semantic level, little consideration is given to accuracy at the phonological level. It is possible children not only name words with high ND more accurately than words with low ND, but also *produce* such words more accurately during development.

Second, graph theory predicts that novel words with high ND should be acquired more quickly compared to forms with low ND (Vitevitch, 2008). If the lexicon does operate under the mechanism of preferential attachment, as graph theory predicts, words with high as opposed to low ND should be acquired faster during acquisition. Facilitated acquisition of such words might occur because they can attach to an existing cluster of words with many phonologically similar forms. In turn, words

with low ND may require additional exposures to become acquired to the same degree. Interestingly, Vitevitch (2008) does not address the possibility that the size of a lexicon might have an impact on preferential attachment. Children and adults thus appear to treat ND in a similar fashion under graph theory. Perhaps though, a developing network may not have sufficient connections to take advantage of any facilitating effects. In the next section, studies of ND on speech production are reviewed across a variety of tasks and populations. For each type of task, findings are discussed relative to predictions of graph theory.

1.1 PRIOR INVESTIGATIONS OF ND ON SPEECH PRODUCTION

Results from the little research that has been conducted on the influence of ND on speech production have been largely confounded by a failure to adequately control for other influential variables such as PP (defined earlier) and *neighborhood frequency* (the average frequency of occurrence of a word's neighbor), both of which have already been shown to significantly affect perception (Vitevitch & Luce, 1998, 1999; Luce & Pisoni, 1998; Cluff & Luce, 1990). Moreover, the majority of studies exploring ND have also involved simultaneous manipulations of PP (Storkel et al., 2006; Heisler, 2004; Vitevitch et al., 2004). This is especially problematic given that words with high ND are composed of similar, frequently-occurring sound sequences; therefore, an important positive correlation exists between PP and ND (Vitevitch, Luce, Pisoni, & Auer, 1999; Storkel & Rogers, 2000). This correlation highlights the need for even more control for PP while investigating ND to isolate any pure effects.

The following overview discusses selected research related to ND and three tasks of varying nature that are relevant to this dissertation. It may be the case, especially considering the inconsistency of previous findings, that effects of ND are task-dependent. First, picture-naming studies conducted with children and adults will be presented. Second, studies on the effects of ND on perceptual identification by adults will be considered. Finally, two word learning studies that manipulated ND will be discussed. The specific tasks utilized in these studies can offer diverse and valuable insight into how ND influences the speech production system during naming, word repetition in ecologically valid circumstances (i.e., background noise), and novel word learning contexts.

1.1.1 Influence of ND on children's naming. In order to understand how ND impacts naming skills in children, Newman and German (2002) administered a naming task to 273 children with typical language development, aged 7 to 12 years, divided into six age groups for comparison. Open-ended sentences (e.g., "The opposite of black is ____.") and colorful illustrations of words (e.g., "These are all ____.") were used to index naming skills. ND was calculated for two subsets of 36 words (18 with low ND, 18 with high ND). The lists were matched for word frequency and age-of-acquisition, but notably not for other confounding variables like PP. Results showed that words with low ND were produced more accurately than words with high ND (low ND > high ND). No interaction of ND and age was found, suggesting the effect was stable with age. Newman and German interpreted the results as stemming from lexical competition. On words with high ND, children may have failed to select the

appropriate target phonological form due to inhibiting competitors; however, they argued, the correct area of lexical space was presumably accessed because otherwise an effect of ND would not have been observed at all. In other words, if items with low and high ND provided equal amounts of competition during naming, a null effect should have been found.

In a related study, German and Newman (2004) sought to determine how the influence of ND might impact naming accuracy and the kind of naming errors produced by children with word-finding impairment (WFI). Although children with typical language development and those with WFI differ with respect to how quickly words are retrieved, words actually known are comparable. Open-ended sentences (e.g., “You cut food with a ____.”) and colorful illustrations were presented to 30 school-age children with WFI. Word-finding errors were noted during the following instances: producing the wrong word (a *substitution* error), mispronouncing the word, responding with “I don’t know”, describing the intended referent, or responding correctly following a 3- to 4-second delay (a *blocked* error). Comprehension was assessed on all erred items in order to differentiate word-finding errors from unknown words. During comprehension probes, participants were asked to select the erred target referent from a visual field of three, one of which included the target word. Items a child did not understand were excluded from the analysis. Results indicated a significant effect of ND for the blocked error pattern. In contrast to the typically developing children evaluated by Newman and German (2002), children with WFI were *less* accurate naming words with low ND than those with high ND (high ND >

low ND). German and Newman hypothesized that, for children with WFI, the access paths to words with low ND are weaker due to fewer neighbors that can facilitate retrieval.

During a second analysis, German and Newman (2004) compared the ND for each target word and its corresponding substitution error, if any, and then averaged this difference across each child. A main effect of ND was found: Substituted words were higher in ND than the target word (high ND > low ND). German and Newman concluded that words with low ND were more difficult for children with WFI to name. In their discussion, the authors acknowledge that the results are in direct contrast to their previous study (Newman & German, 2002). In order to explain their current finding, they argued that other uncontrolled factors of the stimuli, such as neighborhood frequency, may have had an effect.

1.1.2 Influence of ND on adult naming. Given that children's lexicons are significantly smaller than those of adults, examining effects of ND on adult speech production would also be informative. This can help determine if differences exist between adults and children with respect to ND. Newman and German (2005) administered three naming tasks to 1,075 adult participants (aged 12 to 83 years) with typical word-finding abilities. Word-finding abilities were determined from the administration of a naming probe whereby learners whose scores were two standard deviations below their age mean were excluded. Tasks involved picture naming, open-ended sentences, and category identification. The NDs of 44 selected target words were calculated, and then divided into low and high values (22 words per list). The

words were matched for word frequency, familiarity, and age-of-acquisition, but importantly not for PP or neighborhood frequency. Three age groups were analyzed for comparison: adolescents (under 20 years), young adults (ranging from 21 to 49 years), and older adults (aged 50 years or above). A significant effect of ND was found, as was an interaction between age and ND. Across age, naming accuracy was highest on words with low ND (low ND > high ND). A larger effect was noted for adolescents than for the other two age groups. Closer examination of the adolescents' data revealed that the effect of ND declined over the teenage years (strongest at 12 years, weakest at 18 years of age). Newman and German (2005) concluded that, as with typically-developing children, adolescents and adults more easily name words with fewer neighbors, which may be due to less lexical competition during production of low as opposed to high ND words.

Despite the general consistency in findings across their two studies (children with WFI aside), neither of Newman and German's prior studies controlled for the well-documented interaction between ND and PP. In an attempt to address this interaction, Vitevitch et al. (2004) showed 25 college students 44 black-and-white illustrations corresponding to CVC words varying in PP and ND. Four conditions were created to isolate sublexical (PP) and lexical (ND) contributions: high PP/high ND, high PP/low ND, low PP/high ND, and low PP/low ND words. Participants were asked to name each picture quickly and accurately. Contrary to the researchers' predictions, neither a main effect of ND nor an interaction with PP was observed. Words with high ND were named as accurately as words with low ND (low ND =

high ND). The only effect found was that words with high PP were named more quickly and accurately than those with low PP. Vitevitch et al. (2004) concluded that when PP is controlled for and sublexical processing amounts are held constant between words varying in ND, effects of ND disappear. As such, they argued, sublexical processing might dominate during speech production. Thus, in contrast to prior research findings, ND may not play a role during speech production.

1.1.3 Graph theory and naming. Given the inconsistency of the above findings, it might be informative to examine the results in the context of graph theory (Vitevitch, 2008). While findings by German and Newman (2004) support predictions of graph theory (high ND > low ND), the results of Newman and German (2002, 2005) are in direct contrast to it (low ND > high ND). Recall that graph theory posits that, due to high clustering effects and a positive degree of assortative mixing, neighbors should facilitate one another (Vitevitch, 2008); however, this facilitation may depend on the quality of a network. It is possible that effects of ND may differ for typically developing as opposed to impaired networks (e.g., word-finding impairment).

Alternatively, the *size* of a network may impact how ND affects speech production. Vitevitch (2008) originally conducted his analysis using an adult lexicon consisting of approximately 20,000 words. Children, in contrast, comprehend roughly 8,000 words (Templin, 1957). Perhaps the size of a network increases the amount of facilitation or competition of neighbors, thereby resulting in varying effects for ND.

This possibility will now be considered further in regards to how ND affects the adult perceptual system.

1.1.4 Effects of ND on adult perceptual identification. ND has been shown to influence spoken word recognition across a number of experimental tasks including perceptual identification (i.e., same-different decisions) and lexical decision (i.e., word-nonword decisions, Vitevitch & Luce, 1998, 1999). In contrast, use of speech production measures in these studies has remained limited or has resulted in null effects. For example, Vitevitch and Luce (1998) administered a repetition task with 150 CVC words and 240 CVC nonwords to 30 native English-speaking adults. Four conditions were created: low PP/low ND, high PP/high ND, low PP/high ND, and high PP/low ND. As such, PP and ND were not isolated and instead were simultaneously manipulated. Although Vitevitch and Luce (1998) found a significant difference in response latency between words with low PP/low ND and high PP/high ND, this effect varied based on lexical status. On real words, participants repeated forms with low PP/low ND more quickly than those with high PP/high ND (low > high); on nonwords, the opposite effect was true (high > low). Vitevitch and Luce (1998) concluded that the joint manipulation of PP and ND has opposite effects based on the lexical status of a word (word vs. nonword). Most importantly, and relevant to the current research, no differences in production accuracy were found, suggesting that ND may not influence speech production during word repetition.

As stated, few studies have examined effects of ND on perceptual identification using speech production measures; even fewer have studied the impact

of background noise on such effects, which is more typical for environments encountered on a daily basis (e.g., restaurants, classrooms). Furthermore, not only is there noise in the signal, there is also noise in the listener, such as attentional drift and recency effects (Luce & Pisoni, 1998). In one of the first investigations of its kind, Luce and Pisoni (1998) presented monosyllabic CVC words to adults in the presence of white noise. Stimuli variables that were analyzed for their effect on perception were segmental saliency (i.e., individual phonemes of a word), neighborhood frequency, and ND; no consideration was given to PP. Three signal-to-noise ratios that varied from trial to trial were provided to listeners, and participants were asked to *manually* repeat a target by typing in their response. Note that speech production was not used. Results indicated that words with high ND are repeated less accurately than words with low ND (low ND > high ND), arguably due to a greater number of competing lexical forms.

In a follow-up study, Benkí (2003) sought to quantify the relationship between ND and perception. The signal-to-noise ratio was altered across four conditions, and 120 CVC words and 120 CVC nonwords differing in ND were presented to 43 native English-speaking adults. Once again, stimuli were unmatched for PP and word frequency, which have both shown to influence perception (Vitevitch & Luce, 1998, 1999; Howes, 1952; Savin, 1963). In the study, Benkí (2003) asked participants to type what they heard into a computer using English standard orthography; speech productions were therefore not considered. Each response was scored letter by letter, with letters considered correct if they matched the corresponding stimulus phonemes,

and incorrect otherwise. Findings again revealed that words with low ND facilitated perception to a greater degree than words with high ND (low ND > high ND). Benkí additionally found a temporal restriction for the ND effect, such that the lexical neighborhoods of CVC words were determined primarily by the initial two segments (CV). According to Benkí, this temporal effect best facilitates the perception of the final consonant in CVC words when such words have low ND. Given that words with low ND constrain a smaller set of potential candidates than words with high ND, there is overall less competition. For example, the high ND word “bat” /bæt/ has numerous neighbors that share the initial two segments (e.g., “bag” /bæg/, “bash” /bæʃ/, “bad” /bæd/, etc.), while the low ND word “cause” /kɔz/ has only a few such neighbors (e.g., “call” /kɔl/) that require discrimination. In conclusion, it appears that ND influences perceptual identification (via manual-orthographic productions at least) in the presence of noise, with an advantage for words with low versus high ND perhaps due to lexical competition.

1.1.5 Graph theory and perceptual identification. Note that all of the identification tasks utilized in the above-reviewed studies involved key perceptual components. Interestingly, Vitevitch (2008) does not discuss how ND may differentially influence perception and production; in fact, tasks of production (e.g., naming pictures) and perception (e.g., hearing nonwords) are discussed without distinction in the model. It is thus unclear how findings from prior investigations of ND on perception may relate to those of production in the context of graph theory. As it stands, previous studies of perceptual identification have found that words with high

ND result in decreased perceptual accuracy compared to words with low ND (low ND > high ND; Luce & Pisoni, 1998). These findings seem to be in contrast to predictions of graph theory. Recall that Vitevitch (2008) hypothesized that words with many connections should spread activation to a greater degree than words with low ND (high ND > low ND). What if such activation poses as a *disadvantage* during perception, though? If so, this would suggest that although activation may spread at greater levels between words with high as opposed to low ND, such activation could actually be a detriment during perception.

1.1.6 Word learning as a function of ND: across development. While the majority of word learning studies tend to focus on children, who typically learn new words on a daily basis during the first few years of life, adults arguably also continue to acquire and produce new words, such as field-specific terms. Storkel et al. (2006) hypothesized that the initial stages of word learning commence when a novel construction is heard. Depending on a word's ND (low or high), existing corresponding phonological forms might assist the acquisition process by sustaining the target lexical form in working memory. For example, suppose an adult encounters a novel word with high ND. This form has a greater number of neighbors in the learner's lexicon, compared to a novel word with low ND, which could either inhibit or facilitate its acquisition. Storkel and colleagues explored these possibilities by conducting a word learning study with 32 typical adults; words to be learned varied in ND. Novel objects were paired with unfamiliar words and presented in a narrative context. Stimuli in the study varied in PP and also ND. A total of four conditions were

created to explore individual sublexical and lexical contributions: high PP/high ND, high PP/low ND, low PP/high ND, and low PP/low ND. Learning was assessed via a picture-naming task after one, four, and seven exposures. Both partially and completely correct responses were analyzed to determine contributions of PP and ND on early and late stages of word learning. Partially correct responses (i.e., 2 out of 3 phonemes correctly articulated) were indicative of early learning in the study (Storkel et al., 2006). Overall results indicated that adults learned a higher proportion of words with high versus low ND (high ND > low ND). However, when the type of response (partially correct, completely correct) was analyzed separately, no effect of ND was found for partially correct responses. In fact, a facilitative effect of high ND was only revealed on completely correct productions of words also containing high PP. Storkel and colleagues interpreted the results as indicating that lexical representations and ND do play a key role in word learning. It appears, though, that the role of ND may not come in until later stages of word learning.

Although Storkel et al.'s (2006) findings point to an advantage for words with high ND during adult word learning, these results have yet to be replicated. In fact, the opposite effect was reported in an earlier study by Heisler (2004), who manipulated the ND of eight bisyllabic CVCCVC nonwords. Half of the stimuli were of high ND, the other half of low ND. Speech production measures were collected from 16 college-aged adults as well as 16 typically-developing children during three phases: 1) a pre-test phase, in which participants repeated the eight target nonwords in isolation (prior to any assignment of lexical meaning); 2) a post-test phase, where participants

repeated the target nonwords after they had been paired with a visual referent; and 3) a retention phase, where participants were asked to name the visual objects taught in the study via a picture-naming probe. Results showed that adults and children demonstrated similar patterns. Specifically, words with low ND were produced more accurately in terms of segmental details than words with high ND across all three phases of learning (low ND > high ND). Notably, the inhibitory effect of ND was exaggerated following the pre-test phase, suggesting that when a novel form has lexical information assigned to it, lexical competition increases. Heisler (2004) concluded that words with high ND have many more competing forms; this competition leads to more errors during the learning of words with high ND relative to words with low ND.

1.1.7 Graph theory and word learning. If ND determines which words are most easily learned, it would be important to understand how the organization of the lexicon could lead to such facilitation. In the context of graph theory, note that only findings of Storkel et al. (2006) are consistent with its predictions (high ND > low ND). Graph theory is capable of explaining these results via the mechanism of preferential attachment (discussed earlier). Namely, a new word is most likely to be added to the lexicon if it can connect to a high number of existing neighbors. Still, considering the contrasting results for child participants in Heisler (2004), the size of the lexicon may alter the nature of such findings. It is possible that smaller networks may benefit from acquiring nodes that can connect to *few* existing forms, in order to reduce confusion among existing items (Schwartz, 1988).

1.1.8 Summary. A summary of previous results by task and age is presented in

Table 1.1.

Table 1.1 Selected studies of ND by age and task.

	Naming	Perceptual Identification	Word Learning
Children	low ND > high ND (Newman & German, 2002)		low ND > high ND (Heisler, 2004)
	high ND > low ND (German & Newman, 2004)		
Adults	low ND > high ND (Newman & German, 2005)	low ND = high ND (Vitevitch & Luce, 1998)	low ND > high ND (Heisler, 2004)
	low ND = high ND (Vitevitch et al., 2004)	low ND > high ND (Luce & Pisoni, 1998; Benkí, 2003)	high ND > low ND (Storkel et al., 2006)

As seen above, contrasting effects have been reported for picture naming.

While children and adults with typical development more accurately named words with low versus high ND (Newman & German, 2002, 2005), children with word-finding impairment demonstrated the opposite result (German, & Newman, 2004). And still, one experiment reported no differences at all in terms of naming accuracy (Vitevitch et al., 2004). Regarding tasks of perceptual identification, either no effect of ND has been found (Vitevitch & Luce, 1998), or adults tend to perceive words with low ND more accurately than those with high ND (Luce & Pisoni, 1998; Benkí, 2003). Finally, word-learning studies have reported conflicting results. One study found that adults learn words with high ND best (Storkel et al., 2006), while another reported an

advantage for acquiring words with low versus high ND (Heisler, 2004). Additionally, that same study found that children benefit more from learning words with low ND (Heisler, 2004).

As can be seen from the foregoing literature review, research on the influence of ND during production has yielded inconsistent results. This may be due, at least in part, to uncontrolled factors in the stimuli. For example, nearly all of the reviewed studies simultaneously investigated, or failed to control for, effects of PP. This is problematic given the aforementioned correlation of PP and ND (Vitevitch et al., 1999). Words with low ND tend to have low PP (e.g., “straw” /stɹɔ/), while words with high ND tend to have high PP (e.g., “sick” /sɪk/). It is possible that effects of PP could therefore have influenced results of these prior investigations of ND, especially given robust findings of PP (Storkel, 2001, 2003; Vitevitch et al., 1997; Storkel & Rogers, 2000). Finally, despite an existing correlation between PP and ND, words with low PP can nonetheless have high ND (e.g., “ears” /iɹz/, “trip” /tɹɪp/) and vice versa. Considering all of these possibilities together, reported effects of ND may have been obscured in those studies that involved words with low and high ND that were unmatched for PP. In conclusion, published studies on the influence of ND as the sole variable are scarce.

Aside from confounding stimuli factors, ND may also operate differently depending on the nature of a task. For example, consider word learning. A novel word must first be differentiated from existing lexical items; a new form cannot be acquired if it already is considered to reside in the lexicon. ND may be a robust cue during such

a context, implicating that words with few or many neighbors may best assist in the acquisition of a novel word. Alternatively, given that other cognitive mechanisms are involved in word learning (e.g., working memory, semantic association), these neural processes might obscure any effects of ND. If this is the case, new words might be learned to a similar degree regardless of ND. This would leave participants instead to rely on other cues, such as PP (Storkel, 2001). Since tasks of naming and repetition also require unique cognitive components, ND may influence one of these tasks to a greater degree than another. This possibility may also account for the large inconsistency across previous findings.

Finally, even if ND does influence speech production, adults and children may be impacted differently due to differences in lexicon size. In the adult lexicon, the larger number of representations could result in greater lexical competition among words with high ND. Words with low ND might then have an advantage during production. Nevertheless, a larger lexicon also has the potential for providing high levels of facilitation for words with high ND. This could result in greater production accuracy for words with high as opposed to low ND. Turning now to children, developing lexicons have been found to contain *sparser* neighborhoods, or fewer similarly-sounding forms (Coady & Aslin, 2003). If children's neighborhoods are sufficiently sparse, it is possible that lexical competition that might be evident in the adult lexicon may not influence children's lexicons to the same degree. Likewise, facilitory effects may not be as pronounced if there are fewer forms aiding activation

during production. In summary, age differences may alter both the direction and magnitude of effects of ND on speech production.

1.2 PRESENT PROGRAM OF RESEARCH

1.2.1 Current work. In order to understand how phonological similarity can influence speech production in children and adults, especially given previous conflicting findings, the present work will manipulate the ND of words during several tasks of speech production: Experiment 1 (Chapter 2) will investigate effects of ND during children's picture naming, Experiment 2 (Chapter 3) will study the influence of ND on adult word repetition in the presence of background noise, and Experiment 3 (Chapter 4) will explore how ND impacts word learning in children and adults. These studies will directly test the hypotheses that ND may inhibit speech production due to lexical competition (e.g., Newman & German, 2002, 2005), or rather facilitate production due to activation levels from similarly-structured forms (e.g., Vitevitch, 2002; Storkel et al., 2006). Participants will be typically developing preschoolers and college-aged adults, which will allow for the possibility that ND impacts a developing and fully developed lexicon differently. Numerous aspects of speech production will be considered, such as segmental accuracy, overall degree of approximation, and the lexical nature of error substitutions. These experiments will offer potential insight into how items in lexical neighborhoods may influence one another during speech production.

1.2.2 Predictions. Based on a recent analysis of the lexicon using graph theory

(Vitevitch, 2008), it is predicted that greater production accuracy will be demonstrated on words with high versus low ND during the current experiments of naming, repetition, and word learning. Due to a positive degree of assortative mixing in the lexicon, Vitevitch (2008) argued that activated lexical forms likely facilitate, rather than compete with, one another. Words receiving facilitation from many neighbors should then be produced more accurately than items with low ND, even during acquisition. In particular, the mechanism of preferential attachment in graph theory predicts that novel words with high ND can more easily attach to highly-connected existing words in the lexicon. In turn, words with low ND may require more exposures to be acquired to a similar degree. Finally, given that the size of a network is not a variable discussed by Vitevitch, children and adults are expected to demonstrate similar results under the model. In summary, it is predicted that items in the lexicon will facilitate one another during speech production across a variety of tasks.

1.2.3 Theoretical implications. Given the aforementioned interaction between phonology and the lexicon, there are several theoretical implications for the current program of research. In the event that an effect of ND is found during children's naming and word learning, two theoretical explanations may be able to explain the findings. First, if words with high ND are more accurately produced than those with low ND, this would indicate that children capitalize on words that have many phonologically similar forms. That is, words with high ND might actually *facilitate* productive acquisition of a word. Alternatively, if children benefit from producing/learning words with low ND, this would suggest that lexical items compete

with one another during production. If this is true, advantages for words with low ND (with considerably less competition) should be observed. Similarly, Schwartz (1988) postulated that children might be biased to incorporate new words into their lexicon that are easily discriminated; otherwise, lexical confusion could occur. By manipulating the ND of words during a picture-naming and word-learning task, we will better understand the nature of factors that can influence children's speech productions during development.

Turning now to the adult system, it is presently unknown how ND may interact with a fully developed lexicon and/or sound system. Even under the assumption that neighborhoods in the adult brain are organized in a similar manner as in children, massive differences in vocabulary size might sway any such influences in several directions. First, if words with high ND best facilitate adult speech production, for example during word learning, this would inform us that the larger number of lexical entries in the adult lexicon offers a productive *advantage* for acquiring similarly-sounding words. These words might best facilitate one another's lexical activation due to overlapping segmental similarities. That said, if words with low ND best facilitate adult speech production, perhaps lexical competition affects the production system well into adulthood. If it is true that lexical competition affects children, who have relatively small lexicons, it may affect adults to a greater degree. In other words, the more lexical entries there are, the more competition might exist during production. Lastly, it remains possible that *no* influence of ND may be found on adult speech production. Vitevitch et al. (2004), who reported no effect of ND on production when

PP was controlled for, argued that sublexical processing might dominate during speech production. A null effect of ND in the present research program would further contribute to our understanding of influential processes during production, indicating that lexical processing plays a minor role. Alternatively, any effects of ND on speech production would suggest that lexical processing continues to influence the speech mechanism throughout the lifespan. By manipulating the ND of words during a repetition and word-learning task, we will be better informed surrounding the nature of variables that can influence adults' speech production.

A remaining possibility is that, given the context of a fully developed sound system and lexicon, ND may not influence the speech productions of adults and children to the same degree. For example, Munson (2001) found that adults' performance during a repetition task was not influenced by words differing in PP. However, children of various age groups did demonstrate a main effect of PP. Hence, if no effect of ND is found for adults, yet one is found for children, this finding would suggest that ND is more of a developmental variable; its influence might gradually decrease as the lexical and phonological systems develop over time. This latter result would be consistent with previous work reporting a decreasing effect of ND with age (Newman & German, 2005).

1.2.4 Clinical implications. Aside from theoretical contributions based on the current work, there are also important clinical implications. Evaluating how phonology interacts with the lexicon may provide additional understanding of factors that affect sound and word learning. The first possibility, that words with high ND

might best facilitate speech production, is supported by Storkel's (2004) analysis of the MacArthur Communicative Development Inventories (CDI; Fenson et al., 1993). The CDIs provide an extensive list of words generally known by young children, and have been shown to be a valid and reliable index of early lexical acquisition (Fenson et al., 1993; Dale & Fenson, 1996). Storkel (2004) found that the higher a word's ND is, the earlier it is expected to be acquired. She concluded that words with high ND are more easily acquired because of their similarity to other words in the lexicon. If the results of the present experiments further support Storkel's findings, this information would also be useful for incorporating a lexical variable such as ND into the assessment and treatment of individuals with speech and/or language impairment.

The alternative is that words with *low* ND might offer production advantages. It has already been shown that children with moderate-severe phonological disorders show greater improvements in their sound systems when treated sounds are embedded in words with low rather than high ND (Gierut et al. 1999; Morrisette & Gierut, 2002). These advantages of low ND might also be extended to increasing the size of lexicons of children with language impairment. For example, content words targeted in therapy could have low ND.

Similarly, the findings from the proposed research may also contribute to speech-language therapy for adults with acquired language impairment. For instance, adults with aphasia demonstrate an array of language impairments, which may include word-finding deficits and phonological substitutions (Gordon, 2002). Given the important lexical nature of ND, the implications of the current research could also help

guide the assessment and treatment of word-finding deficits. Few studies have yet to investigate the influence of ND on the adult speech production system; therefore, the present research studies may offer directions for future research on how such a variable could be incorporated during treatment of adult language impairment.

CHAPTER 2

Experiment 1:

Children's naming as a function of neighborhood density

2.0 EXPERIMENT INTRODUCTION

2.0.1 Production during naming: beyond semantics. The influence of ND on speech production has been investigated using a variety of experimental tasks including picture naming. Still, the extent to which production has been measured on such tasks remains largely restricted to a semantic analysis (Newman & German, 2002; German & Newman, 2004). Little attention has been paid to actual *production* accuracy. While a semantic analysis indicates whether or not a child accurately named a lexical form, it does not provide any further detail that may be useful when a production is in error. For example, in studies involving a traditional semantic analysis of picture-naming performance, if a participant produces [wif] for “leaf”, this response is scored as correct. In other words, it is not scored differently from the target production [lif]. Using a measure that evaluates production accuracy might more reliably determine effects of ND.

Consider first a binary measure of accuracy (yes/no; Zamuner, Gerken, & Hammond, 2004). In the above example, [wif] would be scored as incorrect, and thus different from a [lif] production. Such a binary measure can offer insight into how ND influences production at the phonological level; however, a segmental measure might provide even more detail about these influences.

A segmental analysis is designed to credit correct segments, while penalizing incorrect ones (Benkí, 2003; Edwards, Beckman, & Munson, 2004). For instance, [wif] for “leaf” might be awarded 2/3 correct segments (vowel and word-final consonant). Under this type of analysis, though, all errors would be treated equally.

That is, for target “leaf”, [wif] would be scored identically to [if] (2/3 correct segments), though the latter is clearly a worse error, at least as far as similarity to the target form and intelligibility are concerned.

There are additional alternatives for examining accuracy of speech production at the whole-word level, which will be described in more detail below (Ingram, 2002). These measures can help us explore how ND influences the phonological system in terms of word shape and phonological complexity, and they allow for a more detailed analysis of different error types. For example, certain words may be approximated to an overall greater degree than others as a function of their ND.

In summary, a semantic analysis has been used in the majority of previous experiments manipulating ND. Few studies to date have evaluated production accuracy using a binary, segmental, or whole-word measure. Therefore, it is unknown how ND may impact children’s productions during the first few years of life. By including production measures, such as those proposed above, insight may be gained into how ND influences production at the phonological level.

2.0.2 Developmental effects of ND. In addition to analysis limitations, prior investigations of the effects of ND on naming have largely been conducted with adults, and even these experiments have resulted in conflicting findings. Recall that Newman and German (2005) found that adult participants named pictures of words with low ND more accurately than those with high ND. In contrast, Vitevitch et al. (2004) found no difference in naming accuracy: Adults named words with low and high ND to a similar degree. One crucial difference between these two otherwise

similar studies relates to the stimuli. Specifically, Newman and German failed to control for the PP of their stimuli, which has consistently been shown to influence speech production (Vitevitch et al., 1997; Munson, 2001). Conversely, Vitevitch et al. (2004) *did* control for PP and showed minimal effects of ND. It seems possible then, that PP (a sublexical variable) might dominate during speech production, while ND (a lexical variable) may not.

In the two above-mentioned studies, a semantic analysis was used. This is perhaps an appropriate analysis to use with adult participants, who are likely to demonstrate few if any production errors during naming. Children, in contrast, produce speech sound errors during the first several years of language acquisition, which allows for relevant studies to include other types of analyses in addition to a semantic one. A small number of experiments have investigated the influence of ND on children's naming accuracy, but have not included these additional types of analyses.

As reviewed earlier, Newman and German (2002) found that, using a semantic analysis, school-aged children produced words with low ND more accurately than words with high ND. Thus, their findings were consistent with a similar study conducted later with adults (Newman & German, 2005). In order to explain their results, Newman and German (2002) invoked the notion of lexical competition, claiming that children's productions on words with high ND may have been inaccurate due to competition with many similar forms (neighbors). One central flaw in Newman and German's (2002) study again relates to a lack of stimuli control. Since PP was

unmatched between stimuli differing in ND, this confound may have contributed to findings regarding production accuracy.

Note that participants in Newman and German's study were children aged 7 to 12 years. Although a semantic analysis was used to examine effects of ND, no consideration was given to production accuracy. It is possible that ND might also have influenced children's productions at the phonological level. Nevertheless, more detailed measures of accuracy might not have revealed effects of ND, given that school-aged children produce the target phonemes of a language with over 90% accuracy (Waring, Fisher, & Atkin, 2001). Thus, it seems that in order to evaluate how ND affects production accuracy, there must be a sufficient number of (developmental) phonological production errors. Otherwise, influences of ND would not be observed due to ceiling effects. Because children of younger ages (e.g., preschoolers) demonstrate numerous phonological errors (Waring et al., 2001), analyzing ND effects on production for this population would be beneficial for the current experimental question. Finally, by controlling for previously ignored characteristics of the stimuli, such as PP, the singular influence of ND on production accuracy can be determined.

2.0.3 The present experiment. It is currently unknown how a child's production of a word may be influenced by its phonological similarity to other words. The goal of the present study is to determine how lexical entries interact with one another during development with respect to their phonological composition. This can expand our understanding of the developing lexicon, in addition to offering important implications for clinical populations. Consider first the notion of lexical facilitation. If

items in the lexicon *facilitate* one another, words with many similar forms might be produced most accurately. Overlapping phonological segments between words could aid in their productive acquisition. In contrast, if items in the lexicon *compete* with one another during phonological acquisition, children might produce words with low ND more accurately than those with high ND. It is possible that words with few similar forms are more easily discriminated during development, thereby leading to earlier correct phonological representations. If either a facilitory or inhibitory influence of ND is discovered, clinical implications seem possible. For example, a goal of increasing expressive vocabulary for a child with language deficits might include words with low or high ND.

Perhaps though, items in the lexicon do not compete with *or* facilitate one another. If this is the case, the degree of phonological similarity in the lexicon may not influence phonological production accuracy at all. In the event this is found, we will better understand the manner with which items in the lexicon interact, as well as which factors in the lexicon influence children's production accuracy. The latter information can help determine whether to further explore such a factor in treatment studies (as with Gierut et al., 1999).

As stated, previous research of this nature has remained limited to studying participants who were generally beyond the stage of developmental production errors. Additionally, analyses have remained semantic in nature. Therefore, any effects of ND on production accuracy have yet to be determined. In light of these limitations, the goal of the present study is to evaluate influences of ND on production by children

still undergoing phonological acquisition. Analyses must extend beyond semantic naming accuracy and include measures of accuracy at the phonological level (e.g., segmental and featural accuracy). Finally, other contributing lexical and sublexical factors must be controlled for, such as word frequency, PP, and neighborhood frequency. Otherwise, it will be difficult to discern the sole influence of ND, if any. These were the goals of the present study.

2.0.4 Predictions. An effect of ND on speech production has yet to be investigated using a binary, segmental, or whole-word measure of production accuracy, especially when controlling for confounding variables such as PP. As described above, results from previous studies using semantic analyses have conflicted with one another. Based on recent work by Vitevitch (2008), it is predicted that children in the present experiment will demonstrate better performance for words with high ND across different measures of accuracy. Recall from Chapter 1 that graph theory posits that lexical forms likely facilitate one another due to a positive degree of assortative mixing in the lexicon: Words with high ND tend to have neighbors similar in ND. Such forms would thereby be named best due to increased levels of activation from many neighbors. Although Vitevitch offers hypotheses about naming as a function of ND, he makes no predictions for phonological accuracy specifically. If words with high ND are named more accurately than those with low ND at the phonological level, perhaps the aforementioned activation levels also apply during phonological acquisition. It is possible that words with high rather than low ND may

capitalize on such activation levels, thus leading to greater production accuracy at an earlier stage of development.

Nonetheless, prior studies have reported an advantage for naming words with low versus high ND (e.g., Newman & German, 2002, 2005), perhaps due to lexical competition. Assuming that words with low ND have less competition during productive acquisition, these forms may be named more accurately. Lexical competition would then appear to apply not only during naming (i.e., semantic analysis), but also during phonological acquisition (i.e., phonological analyses). Words may act as lexical competitors with one another, thus resulting in increased phonological accuracy for words with fewer phonologically similar forms relative to words with many neighbors.

Of course, a remaining possibility is that words with low and high ND might be produced similarly. In this event, it would seem that while ND may affect other language processes, such as perceptual identification (Luce & Pisoni, 1998) or lexical retrieval (German & Newman, 2004), it might not influence phonological acquisition; rather, additional aspects of the lexicon, such as PP, could be more relevant.

2.1 METHODS

2.1.1 Participants. Children were recruited to participate in the study through a variety of means, including public announcements and distribution of flyers and emails to area colleges and universities, daycare centers, and preschools. Once parents indicated an interest in having their child participate in the experiment, they were

contacted via email or phone for a brief screening. Parents were asked if their children were learning to speak any languages other than English, and if they had any concerns about their child's speech or language development. Children who were monolingual in English and typically-developing according to parent report were eligible to participate in the next experimental phase. If a child spoke more than one language at home or had deficits in hearing, speech, language, or cognition (according to parent report), the child was not eligible to participate in the study.

Following written permission (via Institutional Review Board consent forms approved by both San Diego State University and the University of California, San Diego), the child's parents completed an in-depth questionnaire which addressed the child's speech, language, hearing, and overall development (see Appendix A: Parent Questionnaire for Child Participants). Parents were also provided with a written description of the research program including the motivation, experimental tasks, risks and benefits to the child, and time requirements. Parents were informed that they would be able to withdraw their child from the experiment at any time for any reason without consequences.

Each child participant was administered two standardized speech and language tests to ensure age-appropriate receptive vocabulary and productive phonology (see below for details). Children who scored below one standard deviation below the mean on either test were excluded from the study. When appropriate, the child's test results were shared with the parent upon request along with referrals for speech, language, and/or cognitive services as needed.

Forty-two monolingual English-speaking children (24 females, 18 males) were recruited to participate in the study. A total of 37 children (20 females, 17 males) were ultimately included. Five children were excluded due to a variety of reasons: One child had a hearing impairment that was diagnosed shortly following the experiment; 1 child had spina bifida; and 3 children refused to participate once the task had begun. The average age of children participating in the study was 4;6 (years; months) (sd = 0;8; range = 3;0-5;11).

The *Peabody Picture Vocabulary Test-III* (PPVT-III; Dunn & Dunn, 1997), a standardized test of receptive vocabulary, was administered to all children to verify that receptive vocabulary was within typical limits. The PPVT-III (Dunn & Dunn, 1997) additionally served as an index of overall cognition, given that it has been shown to correlate positively and significantly ($p < .05$) with the *Wechsler Abbreviated Scale of Intelligence* (WASI; The Psychological Corporation, 1999; Freeman, Gregory, Turner, Blasco, Hogarth, & Hayflick, 2007). During administration of the PPVT-III, each child was asked to select a target word spoken by the test administrator from a field of four pictures. The items were presented developmentally, with a starting point based on a child's chronological age. The mean standard score of children participating in the study was 105 (sd = 10; range = 89-124).

The *Goldman Fristoe Test of Articulation, 2nd Edition* (GFTA-2; Goldman & Fristoe, 2000), a standardized picture-naming task, was also administered to all children to ensure age-appropriate productive phonology. This measure helped control

for speech production impairments unrelated to potential influences of ND. The mean standard score of children participating in the study was 111 (sd = 8; range = 85-121).

All children who participated in the study achieved standard scores at or above one standard deviation below the mean on both the PPVT-III and the GFTA-2. This indicated that receptive vocabulary and phonological skills were within typical limits.

2.1.2 Stimuli. Thirty illustrations, half of which depicted words with low ND, and the other half of which depicted words with high ND, were used as stimuli in the present experiment (see Appendix B: Experiment 1 Stimuli). The illustrations were selected from the *Assessment of English Phonology* (Barlow, 2003b), a child-friendly picture-naming probe that has been previously used for the study of phonological abilities of preschool children (e.g., Barlow, 2007). The illustrations were colorful and high in resolution in order to engage the children and maintain their attention. All of the words corresponded to either monosyllabic or bisyllabic forms, thus controlling for concerns that phonological complexity (e.g., syllable and word shape) might impact production accuracy independently of ND.

Consistent with previous investigations (Vitevitch & Luce, 1998; Newman & German, 2002), ND was determined by the number of words that could be created by deleting, substituting, or adding a single phoneme to a target item. ND was calculated with the *Irvine Phonotactic Online Database* (IPhOD; Vaden & Halpin, 2005), an online database of 33,432 words which offers a variety of information about a word's lexical and sublexical properties. Although the database is based on an adult lexicon, previous research has demonstrated that the use of adult lexicons provides comparable

measures of ND with children (Hoover, Storkel, & Kieweg, 2008; Jusczyk, Luce, & Charles-Luce, 1994). Furthermore, given that ND is arguably related to the words an individual knows versus expressively uses, it seems appropriate to use a sufficiently large database even with child participants.

Experimental stimuli were divided at the median value for ND; all words below the median were classified as containing low ND, while those above the median value were considered to have high ND. In the low ND condition, the mean ND was 5.5 neighbors (sd = 2.9; range = 1-9). In the high ND condition, the mean ND was 19.7 neighbors (sd = 10.8; range = 11-42). A one-way ANOVA confirmed that the high ND condition had significantly more neighbors than the low ND condition, $F(1, 28) = 24.07, p < .01$. Also, it should be noted that the difference in mean ND between the low and high conditions is even more pronounced in the present study than in previous related experiments. For example, Vitevitch et al. (2004) reported a mean ND of 15.8 neighbors for words with low ND, and a mean ND of 23.6 neighbors for words with high ND. Therefore, the difference in ND between the two types of stimuli in the present experiment is greater.

It was also necessary to control for a multitude of other lexical and sublexical factors in order to minimize confounding effects obtained in prior research. These variables have previously been shown to affect naming accuracy (Swaab, Baynes, & Knight, 2002; Colombo, Pasini, & Balota, 2006; Funnell, Hughes, & Woodcock, 2006), yet they are rarely controlled for in naming studies exploring effects of ND on production. In the present study, stimuli were carefully selected and statistical analyses

confirmed that the two sets of stimuli (low ND, high ND) did not differ (all $ps > .05$; see Appendix C: Experiment 1 Stimuli Control) in any of the following variables, as calculated with the IPhOD (Vaden & Halpin, 2005), and the Bristol Norms for Age of Acquisition, Imageability, and Familiarity (Stadthagen-Gonzales & Davis, 2006):

- a) word frequency (how frequently a word occurs in a language),
- b) neighborhood frequency (the word frequencies of a word's neighbors),
- c) stress-weighted phonotactic probability (positional segment frequency; biphone frequency),
- d) word length (number of phonemes; number of syllables),
- e) imageability (the capacity of a word's referent to evoke mental images of objects or events; Paivio et al., 1968, when such information was available),
- f) familiarity (how relatively familiar a word is in a language, when such information was available),
- g) visual complexity (as indexed by the size of the graphics file; Vitevitch et al., 2004),
- h) grammatical class,
- i) stress placement (i.e., equally matched for trochaic and iambic stress),
- j) phonological composition (consonant clusters, syllable-final consonants, early and later acquired sound classes), and
- k) age-of-acquisition (the age at which a word is typically acquired, when such information was available).

2.1.3 Design and procedure. The study employed a within-subjects design with ND (low, high) serving as the independent variable, and production accuracy the dependent variable. All participants attended one experimental session and were tested individually. Children were seated at a laptop computer and told that they would be looking at some fun pictures. A high-quality, bidirectional microphone was positioned in close proximity to the participant's lips. A practice item was provided to ensure task comprehension; then test stimuli were presented using Microsoft PowerPoint. Stimuli presentation was randomized for each participant using a true random number generator. Words were elicited spontaneously for each picture with a general question (e.g., "What's this?") or a specific verbal prompt (e.g., "What is she drinking?"). All verbal prompts for each picture were scripted in advance and administered identically to each child. If a child did not know a word, a delayed imitation was obtained (e.g., "It's a snail. What is it?"). The type of response (spontaneous, imitative) was noted and taken into consideration for evaluating accuracy.

2.1.4 Speech sample recording, transcription, and reliability. All single-word speech samples were digitally recorded at a sampling rate of 44.1 kHz directly to a Roland Edirol R-09 digital recorder. Speech samples were backed up on compact discs and stored in a separate, locked cabinet in a research space at San Diego State University.

The children's responses were phonetically transcribed by the investigator, a native English speaker and a speech-language pathologist trained in English phonetics and phonology. Inter-rater transcription reliability was calculated for approximately

17% of speech samples by a research assistant trained in English phonetic transcription. Mean point-to-point transcription agreement reached 96% between listeners (sd = 4%; range = 89%-100%).

2.1.5 Data analysis. In order to thoroughly discern the influence of ND on children's speech productions, four dependent variables were measured for all items in the experiment: 1) semantic accuracy, 2) binary production accuracy, 3) segmental production accuracy, and 4) proportion of whole-word proximity. These measures are described below.

A semantic analysis was conducted in order to replicate previous studies examining effects of ND on speech production (e.g., Newman & German, 2002, 2005). Children's productions were scored as correct if a target item was spontaneously named regardless of its production accuracy. For example, if a child produced [tif] for the word "teeth", this response was scored as *correct* in the analysis because the child had successfully provided the lexical-semantic representation. If a child had produced [noz] (a semantic error), the response would have been scored as incorrect. No responses, ambiguous responses (e.g., [mi] for "teeth"), and "I don't know" were also scored as incorrect, consistent with the methodology of previous naming experiments that have manipulated ND (German & Newman, 2004; Vitevitch et al., 2004). Finally, delayed imitations were also scored as incorrect in this analysis, since the child did not independently name the target word.

A second analysis evaluated overall production accuracy. This type of analysis allowed for the possibility that some production errors could be related to a word's

ND. Using a binary criterion (yes, no), children's responses were scored as correct if they phonetically matched the adult target form (they were produced in an acceptable, adult-like manner), and incorrect in the event of sound omissions, distortions, additions, or substitutions. For example, in the above case of [tif] for "teeth", the production would be marked as *incorrect* in this analysis because of a production error. Dialectal and common variations were not penalized in the analysis (e.g., [vɑz] and [ves] were both accepted for the word "vase").

A third analysis was conducted using a fine-grained transcription procedure outlined in Edwards et al. (2004). This analysis considered the accuracy of production with respect to featural properties of the sounds in target words. Following Edwards et al., each consonant in a child's production was coded for accuracy on a 3-point scale: place of articulation, manner of articulation, and voicing. Each vowel was also coded for accuracy on a 3-point scale: dimension (front, middle, back), height (high, mid, low), and length (lax, tense). One point was awarded for each correct feature; thus, each phoneme could receive a maximum of 3 points. In the former example of the word "teeth" as [tif], a child would receive 3 points for target /t/ (1 point for correct voicing: voiceless; 1 point for correct place: alveolar; 1 point for correct manner: stop), 3 points for target /i/ (1 point for correct dimension: front; 1 point for correct height: high; 1 point for correct length: tense), and 2 points for target /θ/, produced as [f] (1 point for correct voicing: voiceless; 1 point for correct manner: fricative; 0 points for incorrect place) for a total of 8/9 points. As before, dialectal and common variations were not penalized. Lastly, 1 point was deducted from a phoneme if an

epenthetic segment occurred directly before it (or in the case of a word-final addition, directly after it).

A final analysis regarded whole-word production accuracy, a relatively understudied variable that can offer insight into phonological development at the whole-word level. Ingram (2002) proposed four measures of whole-word production accuracy that can be used to examine samples of 25+ words, two of which are relevant to the current experiment. The first measure, the *phonological mean length of utterance* (PMLU), is comparable to Brown's (1973) mean length of utterance with the exception that it determines, roughly, the average amount of phones uttered per word (rather than morphemes per utterance). In calculating the PMLU, points are awarded for each phone produced by a child irrespective of target sounds, with additional points awarded for correct consonants. PMLU is considered a measure of phonological complexity under the assumption that, as a child's productions increase in length and, in particular, in the number of consonants, they likewise increase in complexity. For example, the child that produced [tif] for "teeth" would be awarded four points: one point for each segment, [t], [i], and [f], and an additional point for the correct consonant [t]. Note that the *target* word has a possible PMLU total of 5 (/tiθ/ = 3 phones, 2 consonants).

The words with low ND in the present study had a significantly larger PMLU than those with high ND ($p < .05$); therefore, the PMLU measure by itself was not appropriate. Otherwise, inflated PMLU values might be observed on words with low ND simply due to more opportunities to produce target phonemes. Still, use of a

related whole-word production measure, the *proportion of whole-word proximity* (PWP), was deemed appropriate for the current experiment. PWP is designed to capture overall approximation of target words by dividing a child's PMLU for a given word by the target PMLU for that word. In the above example of "teeth" as [tif], the child's PWP would be $4/5 = .80$. Thus, despite differences in mean PMLU, overall proportions (i.e., approximations) of words with low and high ND could be compared.

Inter-rater reliability was calculated for the scoring measures on approximately 17% of speech samples by a research assistant trained in English phonetics and phonology. Mean scoring reliability was 98% (sd = 2%; range = 92%-100%).

2.2 RESULTS

Prior to statistical analyses, accuracy scores were averaged for each participant across condition (low ND, high ND). Average accuracy rates for each dependent variable are presented in Table 2.1 by condition. A separate analysis of individual means revealed that approximately 97% of participants performed similarly to the overall group (i.e., within two standard deviations of the mean). Accuracy scores were converted to a proportion score and then examined as a function of condition. Proportions were arcsine-transformed to approximate a normal distribution. A one-way ANOVA was completed on the transformed data for each dependent variable (semantic accuracy, binary accuracy, segmental accuracy, whole-word proximity) to determine the effects of ND. For all three phonological analyses, spontaneous productions and imitations were analyzed together given that the majority of

children's responses were spontaneous (more than 70%). Moreover, past studies have found no significant difference in phonological accuracy between imitations and spontaneous productions of words (Paynter & Bumpas, 1977; Siegal, Winitz, & Conkery, 1963; Templin, 1947). A conservative alpha level of .01 was used for all statistical tests to allow for multiple comparisons.

Table 2.1 Mean percentage accuracy rates and standard deviations for children's naming by analysis and condition.

	<i>Semantic</i>	<i>Binary</i>	<i>Segmental</i>	<i>Proportion WWP</i>
Low ND	42.34 (10.33)	70.81 (21.16)	95.78 (4.37)	0.95 (.05)
High ND	48.65 (10.29)	77.66 (19.19)	96.88 (3.11)	0.96 (.04)

2.2.1 Semantic accuracy analysis. The first analysis was used to determine how ND might influence preschool children's naming according to semantic accuracy. An accuracy score was calculated for each child in each condition (low ND, high ND). Scores were then submitted to a one-way ANOVA with accuracy serving as the dependent variable, and ND (low, high) as the independent variable. Results revealed a main effect of ND, $F(1,72) = 8.43, p < .01$. Consistent with predictions, words with high ND were named more accurately than words with low ND.

2.2.2 Binary production accuracy analysis. The next analysis considered effects of ND on production accuracy at the phonological level. Binary accuracy scores (yes, no) were calculated for each participant across condition (low ND, high ND). Data were then submitted to a one-way ANOVA with ND (low, high) serving as the independent variable, and binary accuracy (yes, no) as the dependent variable.

There was no significant effect of ND, $F(1,72) = 2.19, p = .14$. Children did not produce words with low and high ND differently in terms of a binary measure of phonetic accuracy.

2.2.3 Segmental production accuracy analysis. The third analysis served to determine how effects of ND might impact production accuracy at a segmental level during naming. Segmental accuracy scores were calculated for each child in each condition (low ND, high ND). Data were then analyzed in a one-way ANOVA with ND (low, high) designated as the independent variable, and segmental accuracy serving as the dependent variable. No main effect of ND was found, $F(1,72) = 1.52, p = .22$. Segmental accuracy on words with high ND was not significantly different from those with low ND.

2.2.4 Whole-word production accuracy analysis. The final analysis considered differences in production accuracy at the whole-word level. Specifically, the degree to which children were approximating overall word shape as a function of ND was evaluated. PWP was calculated for all children using the child and target PMLU values, then submitted to a one-way ANOVA. PWP was assigned as the dependent variable, and ND as the independent variable. There was no significant difference between words with low and high ND, $F(1,72) = 1.26, p = .27$. Children approximated words with low and high ND to a similar degree.

Figure 2.1 displays average accuracy measures for all four dependent variables by condition. Note that proportions were converted to percentages for ease of viewing.

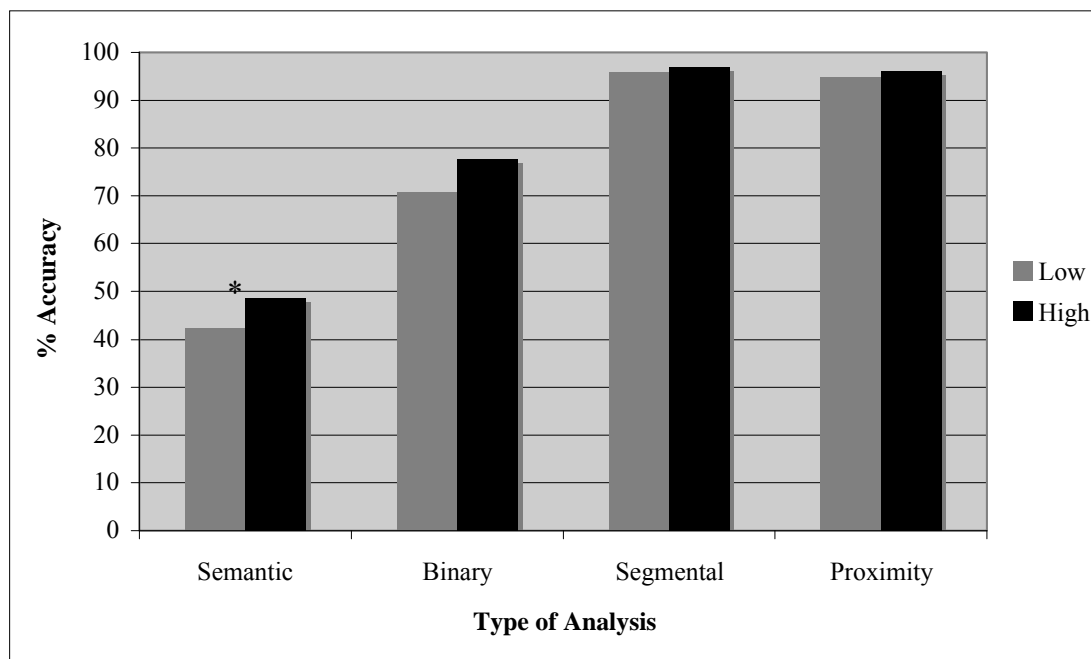


Figure 2.1 Mean percentage accuracy rates for children's naming by analysis and condition.

2.2.5 Summary of results. In summary, children more accurately named words with high ND versus low ND. However, no differences in production accuracy were found for words with low rather than high ND based on binary, segmental, or whole-word measures of accuracy. Hence, target words were produced and approximated to a similar degree regardless of ND.

2.3 DISCUSSION

The current experiment was designed to shed light on how items in the developing lexicon may interact with one another as a function of their phonological similarity: competitively, facilitatively, or neither. Previous studies have failed to control for other influential factors, notably PP, and/or have not considered the

phonological nature of speech productions. The latter limitation is likely rooted in the study of populations who were beyond the age of making developmental production errors. As such, it was not known whether a word's relative ND might impact how accurately it is produced. This information can provide insight into variables that affect production accuracy, which may be useful for working with clinical populations (e.g., children with phonological impairment). In order to address prior limitations, both semantic and productive aspects of children's productions were considered using a picture-naming task in which stimuli solely differed in ND. Results will first be discussed for the semantic analysis, followed by interpretations of the accuracy findings (binary, segmental, whole-word).

2.3.1 Semantic analysis: high ND > low ND. Regarding an influence of ND on semantic accuracy, children more successfully named words with high versus low ND. This finding revealed a facilitative nature of the lexicon, such that words appeared to aid one another during a naming task. In line with original predictions, words with many phonologically similar forms were easier to name than those with few facilitating forms. There are two possible explanations for this result, the first of which is related to graph theory. Recall that due to a larger number of neighbors, greater activation might be provided to words with high as opposed to low ND, as a result of the positive degree of assortative mixing in the lexicon (Vitevitch, 2008). While such activation could potentially inhibit naming of a lexical representation (i.e., via lexical competition), it appears this relationship actually *facilitates* production during children's word naming. That is, words with many neighbors might be more

easily named due to increased levels of surrounding activation. In contrast, only a few neighbors might generate activation for words with low ND. This could result in slower or, in the case of the present experiment, inaccurate naming under time-pressure circumstances (e.g., confrontational naming). For example, children often responded with “I forget,” for words with low ND.

A second possibility relates to the expected age-of-acquisition for a word. Instead of failing to name target forms with low ND, children in the study may simply have known more words with high ND. This confound was addressed by attempting to control for age-of-acquisition. Nevertheless, normative data were not available for all stimuli. Some targets with high ND therefore may be acquired (on average) earlier than those with low ND. Previous work seems to support this notion. Storkel (2004) found that words with high rather than low ND are more easily acquired because of their similarity to other words in the lexicon. In order to remove the possibility of age-of-acquisition confounds, future studies should carefully match conditions on this factor.

2.3.2 Production analysis: high ND = low ND. Although effects of ND were found based on the results of a semantic analysis, no differences emerged in analyses of production at the phonological level. Instead of competing with or facilitating one another, items in the lexicon do not appear to impact one another during productive acquisition simply based on degree of phonological similarity. This was true according to the results of three different measures of production: a binary judgment, a segmental tally, and whole-word approximation. Regardless of ND, words were

produced and approximated to the same degree. It thus appears that a word's ND may not influence children's production accuracy during development. Nevertheless, given that children were highly accurate on the segmental analysis (> 95%), ceiling effects could have masked any effects of ND. One possibility is that these children already passed the developmental stage in which any effects of ND could be discerned on production. Yet, this would not explain the null finding in the binary analysis. Since accuracy was sufficiently low on this measure (approximately 75% across all words), it should have been possible to determine any influence of ND if one existed.

Therefore, participants did exhibit developmental production errors on this task; however, it appears that such errors were just as likely to occur on words with low ND as they were high ND. While ND may impact other domains of language (e.g., perception), it does not seem to influence phonological production accuracy at this stage of development. This is a novel finding.

Perhaps a word's ND does not affect production accuracy due to the amount of phonological detail in the lexical representation. Recall that segmental accuracy was similar for words with low and high ND. Hence, despite original predictions that words with high ND would be best articulated, words with low ND apparently do not seem more difficult to acquire phonologically. It is possible that since preschool children are aware of segmental information (Gerken, Murphy, & Aslin, 2005), words that are low in ND are not less accurately learned during productive acquisition. This might result in similar levels of production accuracy, as was found in the present study.

Finally, results of this study do not preclude the possibility that other factors may play a role in influencing children's production accuracy. Variables such as PP (a related variable), word frequency, or another lexical variable may play a more active role in children's word production accuracy (Maekawa & Storkel, 2006). Studies in the future should determine which of these variables influence children's accuracy by carefully controlling for all other factors, as was done here. Such research can add to our understanding of the developing lexicon and how lexical entries interact with one another during various tasks (e.g., naming, word learning).

2.3.3 Clinical implications. Apart from theoretical contributions of these findings, there are also clinical implications. Given that words with high versus low ND were more accurately named, these words may be ideal targets for children with word-finding deficits (German, 2002). One might argue that having children succeed early (with high ND words) in treatment may increase motivation before presenting more challenging activities. On the other hand, using a complexity approach might be more efficacious (Stanczak, Waters, & Caplan, 2006; Thompson, Shapiro, Kiran, & Sobecks, 2003; Kiran & Thompson, 2003). Kiran and Thompson (2003) showed that targeting atypical exemplars in a category led to improved naming for adults with aphasia for both atypical and typical items. Perhaps words with low ND, which were less accurately named in the present study, may likewise facilitate naming of words with low *and* high ND. Speech-language pathologists could match word naming strategies to specific target words based on their ND, with phonemic cues provided when necessary to improve naming of these forms (German, 2002). Future research is

warranted to determine how incorporating ND into treatment may assist children with word-finding impairment.

The present findings also offer implications for children with phonological disorders. Recall that prior research showed that children with moderate-severe phonological disorders demonstrate greater improvement in their sound systems when target sounds are embedded in words with low as opposed to high ND (Gierut et al., 1999; Morrisette & Gierut, 2002). Importantly, these studies simultaneously manipulated other lexical factors such as word frequency. Given that no effects of ND were found in the current experiment, once all other variables were controlled for, ND should be isolated in future phonological treatment studies. ND may not be a robust variable on its own for inducing sound change. Indeed, Gierut et al. (1999) found that target words with high frequency resulted in the greatest sound change, regardless of ND.

2.3.4 Study limitations. Despite an attempt to control for a variety of factors, limitations to the present experiment must be acknowledged. First, when children did not know a word in the current study, they were provided with a model of the form and asked to imitate it in order to assess production accuracy. This type of response was marked as incorrect in the semantic analysis since the child was unable to name the target. Such a strategy made it difficult to differentiate word-finding errors from unknown words, however. It is uncertain then whether children more accurately named words with high versus low ND due to many facilitating neighbors, or they simply knew more of these words prior to the task. In the future, such possibilities can

be examined by asking children to identify a word via comprehension probes when unable to name it.

Second, given that reaction times were not measured for children's responses, it is difficult to remove the possibility of a speed-accuracy tradeoff for naming words with high ND. Perhaps words with high ND were named more accurately simply because children took a longer time to think about their responses. Notably no time limit was imposed for any picture. Further studies of this nature can measure reaction times to address this possibility.

2.3.5 Summary. In conclusion, this study found that preschool children named words with high ND more accurately than those with low ND. This revealed a facilitative nature of the lexicon but only in terms of *semantic* accuracy. Words with low and high ND were produced with a similar degree of *production* accuracy, regardless of the accuracy measure used. As such, the degree of phonological similarity in the lexicon does not appear to impact production of a word during development. Although differences in production accuracy were not found, it seems likely that ND may affect the degree to which children are able to either name a word or (potentially) learn a word during development. In particular, words with many neighbors may facilitate naming and/or learning due to phonological similarity to other forms. Models of language processing (e.g., graph theory) appear to support this possibility by invoking levels of activation from the neighbors of a word, with greater levels of activation provided to words with a larger number of neighbors. In contrast,

naming of words with few neighbors may be relatively slowed and/or inaccurate due to an insufficient amount of activation.

2.3.6 Future directions. Work in the future in this area should include participants of younger ages to rule out the possibility that ND may be a developmental factor affecting production accuracy at a very young age. It remains to be seen whether such a factor may simply cease to influence production at a certain age due to more influential factors such as PP (Maekawa & Storkel, 2006). As well, experimental studies should be conducted with different populations (e.g., children with typical development, children with word-finding deficits) on the same task. This is necessary in order to investigate the possibility that the status of the naming system may affect the direction in which ND influences word naming (Newman & German, 2002; German & Newman, 2004). Words with high ND may compete with one another in highly developed naming systems, while the same words may facilitate naming in compromised systems or those systems still in the early stages of development (e.g., preschool children). Finally, it would be interesting to examine how bilinguals treat a lexical factor such as ND. Its influence may vary in a language depending upon that language's status for the speaker (e.g., first, second). Languages that are acquired later in life may depend less or more on a factor like ND, given its index of phonological similarity with existing words in both lexicons.

CHAPTER 3

Experiment 2:

Effects of neighborhood density on adult word repetition

3.0 EXPERIMENT INTRODUCTION

Whereas the previous chapter explored effects of ND on children's picture naming, the following chapter will investigate such influences during adult word repetition. Given the notable inconsistency of prior findings discussed in Chapter 1 (Luce & Pisoni, 1998; Vitevitch et al., 2004; German & Newman, 2004), it is important to address the possibility that effects of ND are task-dependent. Different elements of a task may potentially affect the role of ND during speech production. For example, tasks of repetition differ from those of naming with respect to perceptual components. Additionally, children and adults may show differing effects of ND due to aspects of development (e.g., vocabulary growth). In order to pursue both of the above possibilities, the goal of the study in the present chapter is to discern the influence of ND during adult word repetition.

3.0.1 Bridging perception and production: repetition. Recall from Chapter 1 that ND can influence perceptual identification across a number of experimental tasks (e.g., same-different auditory decisions, lexicality judgments; Vitevitch & Luce, 1998, 1999). Specifically, work by Luce and colleagues has shown that words with high ND are perceived less accurately than words with low ND, potentially due to lexical competition (Luce & Pisoni, 1998; Cluff & Luce, 1990; Goldinger et al., 1989). Words with many neighbors may compete with one another during recognition, thereby affording a *perceptual* advantage to forms with few phonological similarities.

The majority of these previous studies did not include any measures of speech *production*. It is therefore uncertain how ND may affect actual production during an

identification task. Even tasks related to repetition have not required oral responses, instead relying on orthographic output. For example, Luce and Pisoni (1998) asked participants to type their perceptions on a keyboard, allowing participants up until 30 seconds to identify a stimulus. Given such a stimulus-response delay, cognitive processes such as reasoning could also have influenced the results. Participants may have decided that a perceived word was too unlikely to occur in English (i.e., word frequency), subsequently settling on another candidate. Such effects of frequency have previously been reported (Savin, 1963; Glanzer & Bowles, 1976; Howes, 1952). By examining the nature of *repetitions* during an identification task, we can better understand how lexical items interact as a function of phonological similarity in this context. Words may indeed compete with one another, as has been shown (low ND > high ND; Luce & Pisoni, 1998), or alternatively, facilitate one another (high ND > low ND).

3.0.2 Previous studies of perception and ND. Despite a sizeable amount of perceptual experiments that have manipulated ND, two major limitations exist with prior work. First, ND has typically been conducted in tandem with other lexical variables. For example, Cluff and Luce (1990) jointly classified stimuli in terms of their ND *and* word frequency. An “easy” word had low ND and high frequency; a “hard” word had high ND and low frequency. Relatedly, Luce and Pisoni (1998) found that words with many neighbors that are of high frequency result in decreased rates of perception. Thus, investigations involving ND have rarely tested a set of stimuli differing only in ND. As such, effects that have been previously attributed to

ND may also be due to related factors (e.g., word frequency, PP). It is important then that stimuli conditions must be matched for word frequency, PP, and other relevant variables.

A second limitation with previous research relates to the type of analysis used. Responses have generally been scored as correct or incorrect (Vitevitch & Luce, 1998, 1999). Consequently, other aspects of production have been understudied such as segmental accuracy. As discussed in Chapter 2, a segmental measure of production accuracy can offer insight into how ND affects production at a more fine-grained level. For instance, although an overall effect of ND may exist during perception, participants may nonetheless perceive similar amounts of segmental accuracy between words with low and high ND. In addition, little to no attention has been paid to the nature of misperceptions during identification tasks. While certain words may be misheard more so than others, how does ND affect what *is* perceived in these instances? Words with low or high ND might be favored as likely candidates during such moments. By examining the nature of repetition errors in the presence of suboptimal listening conditions, we can gain a better understanding of effects of ND as a single variable. This becomes especially relevant given the environments we encounter on a daily basis (e.g., restaurants, classrooms), which is discussed further below.

3.0.3 Noise in the signal. Note that previous investigations have often provided listeners with a high-quality signal (e.g., Vitevitch et al., 2004), even though such conditions do not mirror everyday perceptual circumstances. Although effects of

ND may be found in the laboratory, such influences might be minimized or even exacerbated in typical listening contexts. As reviewed in Chapter 1, studies by Luce and Pisoni (1998) and Benkí (2003) examined the impact of noise on effects of ND. Both experiments reported an advantage for perception of words with low versus high ND. Based on these findings, it would seem then that background noise does not impact ND differently than clean signal conditions, insofar as perception is concerned. Since fewer competing forms exist for words with low rather than high ND, this might lead to a perceptual advantage for low ND words.

Two aspects of the above studies warrant comment. First, stimuli were again uncontrolled for other related factors like PP. This is highly problematic because PP has repeatedly been shown to influence speech perception (Vitevitch & Luce, 1998, 1999; Vitevitch et al., 1997). It is therefore difficult to determine the sole influence of ND in these studies. Second, repetitions were not collected on either task; participants typed in their responses. It is unclear then how ND may have impacted speech production during these experiments. Lexical competition may have been operating, leading to greater repetition accuracy for words with low ND. Still, the possibility remains that words with high ND may have facilitated one another during repetition. Given the above limitations, the influence of ND on word repetition has yet to be fully explored. Potential factors of interest include the accuracy of repetitions as well as the nature of misperceptions.

3.0.4 The current experiment. It is presently unknown how items in the lexicon may interact with one another during word repetition: competitively,

facilitatively, or neither. Previous work has proposed that words with low ND are perceived best due to lexical competition (Luce & Pisoni, 1998; Cluff & Luce, 1990); however, results from these prior studies have often been confounded due to other influential factors like PP. In order to differentiate effects of ND from other such variables, a task must first be created where stimuli differ solely in ND. Additionally, by eliciting repetitions (as opposed to orthographic responses), cognitive processes such as reasoning can be minimized given a shorter response period (e.g., 3 seconds). This is a reasonable assumption since the time it takes to repeat a word is significantly less than when typing a word. By limiting the response time, the nature of the lexicon can more reliably be examined during repetition. If words do compete with one another, then words with many phonological similarities should be at a disadvantage. Perhaps words with low ND are more perceptually salient given that they resemble few other words. On the other hand, if items in the lexicon *facilitate* repetition of one another, words with high ND should be repeated more accurately than those with low ND. It is possible that the number of words sharing common phonological segments enhances repetition accuracy. Lastly, if additional sublexical and lexical variables play larger roles than ND during repetition (e.g., word frequency, PP), a word's phonological similarity may not affect accuracy at all.

Let us assume for a minute that, based on prior work (Luce & Pisoni, 1998; Benkí, 2003), lexical competition *does* result in a perceptual advantage for words with low versus high ND. It is still unknown whether such competition may operate domain-specifically (only during perception), or more domain-generally (during both

perception and production). The current experiment can offer clarification on this issue by examining the nature of misperceptions. Namely, when a word is misperceived, is its substituted form likely to be lower, equal, or higher in ND? If lexical competition acts only during perception, individuals may be as likely to substitute targets with low ND words as they are with high ND words. If, on the other hand, lexical competition acts both in perceptual and productive domains, substitution errors should result in forms that are *lower* in ND than the target. If perception is impaired (e.g., background noise), words with low ND might have less competition and be more likely to serve as substitutes. Alternatively, words with high ND could be perceived to a greater degree during such moments given their resemblance to many other forms in the lexicon. In this case, low ND words would not be expected to occur as substitutes for such forms.

The current experiment will add to our understanding of the nature of the lexicon by considering both repetition accuracy and the nature of repetition errors. Not only will we better understand which kinds of words are most accurately repeated, we will also discover the *nature* of what tends to be repeated during moments of misperception. In order to ensure there is an adequate number of potential misperceived errors to analyze, background noise must be added to the stimuli. This is warranted given that previous repetition studies have not always found effects of ND in ideal listening conditions (e.g., Vitevitch & Luce, 1998). Likewise, Luce and Pisoni (1998) argued that without noise, a repetition task would simply be one of phonetic perception with minimal consequences for recognition.

3.0.5 Predictions. Predictions for the current study relate to two variables: repetition accuracy and the nature of misperceptions. First, due to a positive degree of assortative mixing in the lexicon, Vitevitch (2008) argued that words should *benefit* from the activation of their neighbors. Thus, it is expected that participants in this experiment will more accurately repeat words with high as opposed to low ND. Instead of competing with one another, lexical forms that are simultaneously activated may provide more rapid access to a target via shared phonemes. This faster access during a time-pressure task (i.e., repetition) could result in increased accuracy. In contrast, if the aforementioned activation is *inhibitory*, words with low ND might be repeated more accurately. Since fewer forms are presumably activated during perception of words with low versus high ND, the amount of lexical competition is likely reduced. This would be consistent with prior findings of decreased perceptual accuracy for words with high versus low ND (e.g., Luce & Pisoni, 1998; Cluff & Luce, 1990).

Next, consider the nature of misperceptions. Previous investigations have found that when a word is unknown, participants with word-finding impairment substitute forms that are higher in ND (German & Newman, 2004). Similarly, when misperceptions occur in the present study, it is predicted that participants will produce words that are higher in ND than the target. If this is found, and words with high ND are also perceived best, such findings would suggest lexical facilitation impacts perception and production similarly. Alternatively, if lexical facilitation operates differently during perception and production, adults might substitute target words with

forms that are *lower* in ND. Finally, if ND does not affect misperception at all, adults in the present experiment may tend to substitute similar amounts of words with low and high ND.

3.1 METHODS

3.1.1 Participants. Forty-six students (44 females, 2 males) from the School of Speech, Language, and Hearing Sciences at San Diego State University were recruited to participate in exchange for extra course credit. The average age of individuals participating in the study was 23 (sd = 3; range = 21-33). Once adult participants provided written permission (via Institutional Review Board consent forms approved by both San Diego State University and the University of California, San Diego), they completed an in-depth questionnaire which addresses the participant's speech, language, hearing, and overall development (see Appendix D: Questionnaire for Adult Participants). Participants were also provided with a written description of the research program including the purpose, procedures, risks and benefits, and time requirements. Participants were informed that they would be able to withdraw from participation in the experiment at any time without consequences. All participants were native speakers of English and reported no history of speech, language, hearing, or cognitive impairment.

3.1.2 Stimuli. Eighty monosyllabic words, half of which had low ND, and the other half of which had high ND, were used as stimuli in the present experiment (see Appendix E: Experiment 2 Stimuli). ND was defined in an identical manner as in

Experiment 1, using a one-phoneme metric, and calculated with the same online database of 33,432 words (Vaden & Halpin, 2005).

Experimental stimuli were divided at the median value for ND; all words below the median were considered to have low ND, while those above the median value were classified as containing high ND. In the low ND condition, the mean ND was 6.8 neighbors (sd = 2.0; range = 3-9), and the mean ND in the high ND condition was 19.7 neighbors (sd = 7.3; range = 12-43). Note that these values are nearly identical to the respective conditions in Experiment 1. A one-way ANOVA confirmed that words in the low ND condition had significantly fewer neighbors than those in the high ND condition, $F(1,78) = 116.79, p < .01$. Additionally, the mean ND of the low condition in the present study is significantly lower than in prior experiments. For example, Vitevitch and Luce (1998) reported a mean ND of 40 neighbors for words with low ND, and a mean ND of 56 neighbors for words with high ND. Therefore, the difference in ND between the two conditions in the current study is greater.

As described earlier, it was crucial to control for confounding variables that have shown to affect speech perception and production (Vitevitch & Luce, 1998, 1999; Savin, 1963; Vitevitch et al., 2004; Newman & German, 2005). Although stimuli differed in ND, they were not significantly different (all $ps > .05$; see Appendix F: Experiment 2 Stimuli Control) in any of the following factors:

- a) word frequency (how frequently a word occurs in a language),
- b) neighborhood frequency (the word frequencies of a word's neighbors),

- c) stress-weighted phonotactic probability (positional segment frequency; biphone frequency),
- d) word length (number of phonemes; number of syllables),
- e) grammatical class,
- f) phonological composition (e.g., consonant clusters, sound class), and
- g) duration (described in detail below).

In addition to the above variables, words with low and high ND were matched for initial phonological segments. For instance, a word with low ND was “grudge”; a word with high ND was “grand”. This was necessary to control for sensitivity to various initial segments of stimuli (Vitevitch & Luce, 1998; Benkí, 2003).

All stimuli were digitally recorded directly to a Roland Edirol R-09 digital recorder at a sampling rate of 44.1 kHz, using a high quality, bidirectional microphone. Stimuli were recorded in a sound-attenuated booth (IAC Controlled Acoustical Environment). A female native speaker of English, who speaks with a General American English dialect, read aloud each item at a normal speech rate, taking care to pronounce each form with a similar inflection. Differing prosodic intonations due to list-reading were further minimized by including “filler” words at the beginning and end of each word list. Stimuli were normalized using Adobe© Audition recording software, adjusting the overall level of each stimulus so that the amplitude peaks were similar, then spliced into individual 16-bit WAV files at a sampling rate of 44.1 kHz. The mean duration for all words was measured twice for reliability purposes. Words with low ND had a mean duration of 670 milliseconds (sd

= 102); words with high ND had a mean duration of 704 milliseconds ($sd = 173$). This difference was not statistically significant, $F(1,78) = 1.13, p = .30$. Words were randomized using a true random number generator. A screening of the words was then conducted with a different native speaker of English, who identified single-word speech samples with 100% accuracy. This indicated that the recordings were intelligible and of high quality.

In order to dilute the listening signal, speech spectrum shaped noise was mixed with the stimuli at an appropriate signal-to-noise ratio (SNR, described below). Briefly, speech spectrum-shaped noise has a spectrum which approximates the average long spectrum heard in typical speech, and serves as a more realistic type of noise (versus white noise, for example) that occurs in everyday situations (Crandell, 1991; Plomp, 1986). Consistent with previous related tasks (e.g., Choi, Lotto, Lewis, Hoover, & Stelmachowicz, 2008), the noise began 50 milliseconds before the beginning of each word, and lasted for 50 milliseconds following the end of each word.

The next step involved identifying an appropriate SNR for the task. Three SNRs were piloted with native speakers of English: -2 dB, -3 dB, and -4 dB. Overall repetition accuracy was 90% at -2 dB, 30-40% at -3 dB, and 20% at -4 dB. Based on pilot testing, -3 dB was selected as the target SNR ratio for this task, considering that other SNRs might yield either too low or too high of a task performance. Furthermore, Benkí (2003) found a main effect of ND using a similar SNR.

3.1.3 Design and procedure. The study employed a within-subjects design

with ND (low, high) serving as the independent variable, and repetition accuracy and difference in ND as the dependent variables. All participants attended one experimental session and were tested individually. Participants were told that they would be hearing words over some background noise, and were instructed to repeat each word as quickly and accurately as possible. All participants were strongly encouraged to produce a response even when they were uncertain of a word; this ensured a sufficient number of repetition errors to analyze. A high-quality, bidirectional microphone was positioned in close proximity to the participant's lips. Presentation of stimuli was controlled by Sound Studio© digital editing software and played over Sony MDR-7506 headphones at a comfortable listening level.

Each participant received three practice trials. These trials were used to familiarize participants with the nature of the task; practice trials were not included in the final data analysis. Pilot studies confirmed that three trials were sufficient to familiarize participants with the task. The task was then administered. Stimuli presentation was randomized for each participant using a true random number generator. After each stimulus was presented, participants had exactly three seconds to repeat what they heard (Vitevitch & Luce, 1999). Otherwise, a "no response" was scored and the next word was automatically presented. By limiting the amount of time a participant could respond, cognitive processes which may have intervened during the task (e.g., reasoning) were likely minimized. Note that this methodology differs from previous studies, where participants had up until 30 seconds to respond (Luce & Pisoni, 1998).

3.1.4 Speech sample recording, transcription, and reliability. All single-word speech samples were digitally recorded at a sampling rate of 44.1 kHz directly to a Roland Edirol R-09 digital recorder. Speech samples were backed up on compact discs and stored in a separate, locked cabinet in a research space at San Diego State University.

Participants' responses were phonetically transcribed by the investigator, a native English speaker and speech-language pathologist trained in English phonetics and phonology. Inter-rater reliability was calculated for approximately 15% of speech samples by a research assistant trained in English phonetic transcription. Mean point-to-point transcription agreement reached 98% between listeners ($sd = 3\%$; range = 92%-100%).

3.1.5 Data analysis. Three dependent variables were measured for all experimental items: 1) binary production accuracy, 2) segmental production accuracy, and 3) difference scores between targets and misperceptions.

The first analysis evaluated overall production accuracy. This type of analysis allowed for the possibility that some repetition errors could be related to a word's ND. Using a binary criterion (yes, no), participants' responses were marked as correct if all phonetic segments identically matched the target. Responses were otherwise marked as incorrect, including no responses. Dialectal variations were not penalized (e.g., /kɑlz/ and /kɔlz/ were accepted for "calls"). Note that this type of analysis is consistent with Experiment 1 and earlier studies of this nature (e.g., Vitevitch & Luce, 1998, 1999).

A second analysis considered production accuracy with respect to featural properties of the sounds in target words. This type of analysis followed a fine-grained transcription method outlined in Experiment 1 (Edwards et al., 2004). Phonemic additions were addressed by deducting one point from a phoneme if an epenthetic segment occurred directly before it (or in the case of a word-final addition, directly after it).

Finally, a third analysis explored the nature of a misperception (e.g., “chest” for “taste”) with regards to ND. This comparison was conducted in order to investigate the possibility that erred productions might be lower or higher in ND than the target. Such findings could indicate an inhibitory or facilitory influence of ND on speech production. Using the previously mentioned database (Vaden & Halpin, 2005), ND was calculated for all productions regardless of accuracy. “No responses”, nonwords (e.g., [fɹɪt] for “fruit”), or words not found in the database (e.g., “drudge”) were excluded from such analyses.

Inter-rater reliability was calculated for scoring on approximately 15% of speech samples by a research assistant trained in English phonetic transcription. Mean scoring reliability was 97% (sd = 2%; range = 92%-100%).

3.2 RESULTS

Prior to analyses, each participant’s production accuracy was averaged across condition (low ND, high ND). Average accuracy rates for the production analyses are provided in Table 3.1 by condition. A separate analysis of individual means revealed

that all participants performed similarly to the overall group (i.e., within two standard deviations of the mean). Accuracy scores were converted to a proportion score and then examined as a function of condition. Proportions were arcsine-transformed to approximate a normal distribution. A one-way ANOVA was completed on the transformed data for each dependent variable (binary accuracy, segmental accuracy, difference scores) in order to investigate the influence of ND on word repetition. A conservative alpha level of .01 was used for all statistical tests to allow for multiple comparisons.

Table 3.1 Mean percentage accuracy rates and standard deviations for adult word repetition by analysis and condition.

	<i>Binary</i>	<i>Segmental</i>
Low ND	33.21 (8.13)	73.56 (5.24)
High ND	40.27 (9.34)	78.05 (4.44)

3.2.1 Binary production accuracy analysis. The first analysis considered how ND might influence word repetition using a binary measure. Accuracy scores (yes, no) were calculated for each participant across condition (low ND, high ND). Data were then analyzed in a one-way ANOVA with ND (low, high) serving as the independent variable, and binary accuracy (yes, no) as the dependent variable. There was a main effect of ND, $F(1,90) = 14.74, p < .01$. Consistent with predictions, words with high ND were more accurately repeated than words with low ND.

3.2.2 Segmental production accuracy analysis. In the next analysis, fine-grained differences in responses were evaluated relative to the target. Accuracy scores

were calculated for each participant in each condition (low ND, high ND) and submitted to a one-way ANOVA. Segmental accuracy served as the dependent variable, and ND (low, high) as the independent variable. A significant effect for ND was found, $F(1,90) = 19.63, p < .01$. Again, participants repeated words with high ND with greater accuracy than words with low ND. Figure 3.1 illustrates the average accuracy rates for the binary and segmental analyses.

3.2.3 Target-misperception comparison. A final analysis compared the ND of misperceptions with those of target words. The difference in ND between targets and errors was calculated and submitted to a one-way ANOVA. Difference in ND served as the dependent variable, and ND (low, high) as the independent variable. The difference was significant, $F(1,90) = 368.30, p < .01$. As predicted, and a novel finding, erred repetitions (due to misperception) tended to be higher in ND than the target form. Means for targets and errors are displayed in Table 3.2 and depicted in Figure 3.2.

Table 3.2 Means and standard deviations of neighborhood density for adult word repetition by response type.

<i>Target Words</i>	<i>Substitutions</i>
13.24 (8.40)	18.38 (1.82)

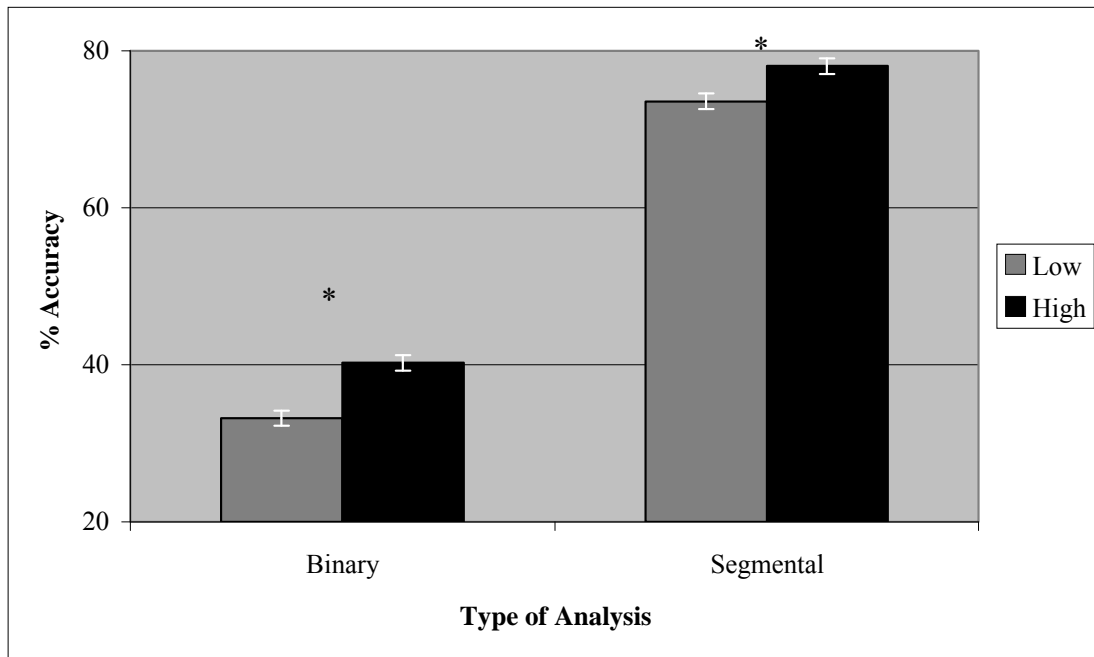


Figure 3.1 Mean percentage accuracy rates for adult word repetition by analysis and condition.

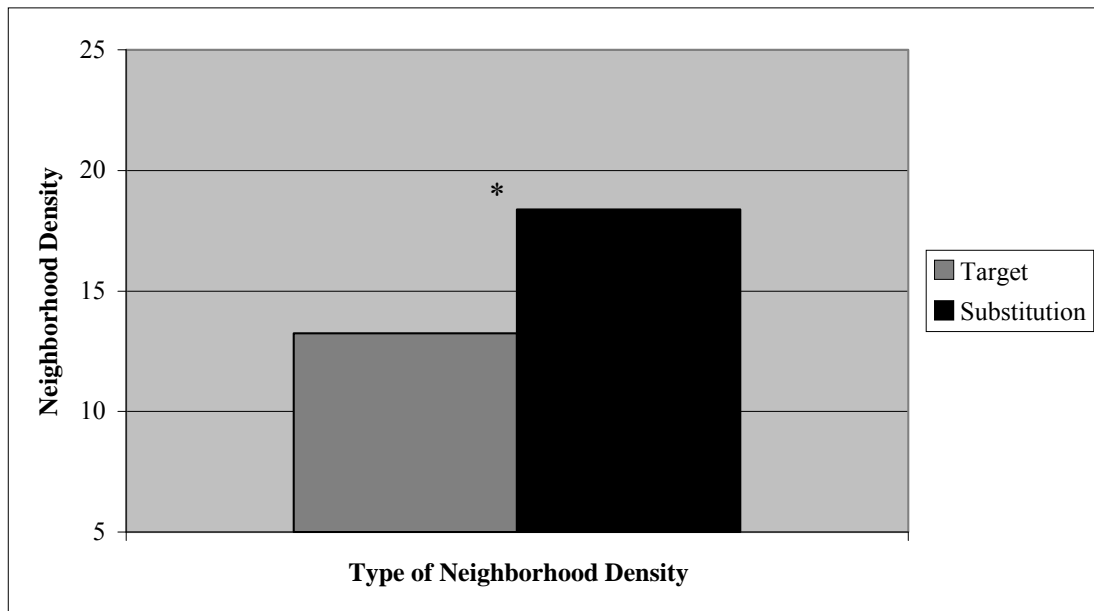


Figure 3.2 Comparison of neighborhood density between targets and substitutions during adult word repetition.

3.2.4 Summary of results. In the present experiment, words with high ND were more accurately repeated than words with low ND. This was true using both a binary and a segmental measure of production accuracy. Additionally, it was found that when perception was compromised, substituted forms tended to be higher in ND than the target word.

3.3 DISCUSSION

The primary purpose of the current study was to determine the influence of ND on adult word repetition in a noisy condition. Both repetition accuracy and the nature of an error were examined. Previous studies have failed to control for confounding factors such as PP and/or have not used speech production measures. Thus, this experiment served to inform us of how lexical items may interact with one another during word repetition: competitively, facilitatively, or neither. This knowledge may be useful for understanding how ND can affect speech production under different circumstances (e.g., naming, repetition). Additionally, by examining the nature of substitutions, light can be shed onto how ND impacts domains differently. For example, lexical competition may operate during perception but not production. Lastly, there may be academic implications for this line of work (e.g., classroom settings). Results will first be discussed for the accuracy components of the task (binary and segmental analyses), followed by an interpretation of the error analysis.

3.3.1 Past and present: more pieces to the ND puzzle. Despite over a decade of consistent findings that words with low ND are perceived more accurately than

words with high ND (e.g., Luce & Pisoni, 1998), results in the current experiment appear to suggest otherwise. For both the binary and segmental accuracy analyses, consistent with predictions, words with high ND were repeated more accurately than words with low ND. This finding has not been reported in prior research, regardless of the quality of the speech signal (e.g., background noise). In order to interpret this unexpected result, a brief discussion of prior work may first be helpful.

In their pioneering study, Luce and Pisoni (1998) calculated the ND of over 800 words to assess an effect on perceptual identification. While the majority of past studies have cited Luce and Pisoni as their operational definition of ND (i.e., using a one-phoneme metric), this in fact is an oversight. Closer examination of Luce and Pisoni's (1998) study yields that lexical neighborhoods were calculated by *degree of phonetic overlap*. Dubbed “segmental confusability”, the neighbors of a target word were determined based on how similar individual segments were to one another. In the study, a neighbor for /kʌt/ was /skɪd/; a neighbor for /dɔg/ was /tæg/. Note that under the more traditional one-phoneme metric, none of these word pairs would be considered neighbors. For example, /kʌt/ and /skɪd/ differ by three phonemes although both forms contain velar stops, lax vowels, and word-final alveolars. In a follow-up study, Benkí (2003) used the same segmental confusability method of calculating lexical neighborhoods. Unsurprisingly, his results replicated Luce and Pisoni (1998), finding an advantage for perceiving words with low over high ND.

Now consider the effect that different definitions of ND might have on classifying stimuli. If neighbors are determined by the degree of phonetic overlap, it is

possible that words would have *greater* ND than when using a one-phoneme metric. For example, the word “dog” has 11 neighbors according to a traditional definition of ND (Vaden & Halpin, 2005), and would have low ND in the present study. In contrast, the same word may have had high ND in Luce and Pisoni (1998) due to overlapping phonetic similarities with many additional words (e.g., “leg”, “duck”, “smog”, “take”). Perhaps then conflicting findings are due to different definitions of phonological similarity (in addition to other factors that may have influenced prior research e.g., PP). Still, it should be noted that, Luce and Pisoni (1998) and Benkí (2003) aside, nearly every other study of ND over the past decade has defined phonological similarity using a one-phoneme metric (Vitevitch & Luce, 1998, 1999; Coady & Aslin, 2003; Gierut et al., 1999; Storkel et al., 2006; Newman & German, 2002, 2005; Morrisette & Gierut, 2002; Vitevitch, 2002, 2008; Heisler, 2004). As such, the present study defined ND in a manner that is more consistent with the literature. Past studies of perception using a standard definition of ND were not conducted in noise; therefore, it is difficult to compare them with the current findings since differences in accuracy were not found in ideal listening conditions (Vitevitch et al., 2004; Vitevitch & Luce, 1998, 1999). Future work should attempt to replicate the present findings by using a traditional one-phoneme definition of ND during tasks of noise-induced repetition.

3.3.2 Theoretical considerations. Studies in the past have proposed that lexical competition can account for the observed perceptual advantages for words that are low in ND. If a word has many phonologically similar forms, greater competition

might exist for recognition, hindering accurate perception. Yet, words with high ND, as determined by the one-phoneme method of ND calculation, were repeated most accurately in the present study. What can account for this finding? Recall from graph theory that the lexicon has a positive degree of assortative mixing (Vitevitch, 2008); words that are highly connected tend to be connected to one another. Words with low ND, in contrast, tend to have neighbors that are also low in ND. Vitevitch (2008) proposed that if a target form is temporarily inaccessible in the lexicon (i.e., activation levels do not reach a certain threshold), a nearby lexical candidate may be selected. In other words, partial information about a target form can still be accessed (e.g., the first two sounds, the final consonant). Perhaps words with high ND offer such information to a greater degree than those with low ND. Previous studies appear to support this notion (Vitevitch & Sommers, 2003; MacKay & Burke, 1990). MacKay and Burke (1990) found that during tip-of-the-tongue states, participants were able to provide more segmental detail about words with high versus low ND.

In the current study, words with high ND may have facilitated perception best due to activation from many phonologically similar forms. Thus, instead of increased competition (Luce & Pisoni, 1998; Vitevitch & Luce, 1998), perhaps there are increased levels of *facilitation* in the lexicon during production. Such possibilities have been demonstrated previously. Vitevitch (2002) found that more “slips of the tongue” were made on words with low versus high ND. He argued that during speech production, multiple lexical forms are activated that facilitate, rather than compete with, one another. According to the current results, it seems that repetition may also

benefit from multiple activated lexical forms. The levels of activation that a target item receives from its neighbors, through shared phonological representations, might aid in final selection/repetition of the target word. Along the same lines, a phonologically similar word may be produced when the target item is not activated sufficiently.

An alternative explanation for the present findings involves a potential speed-accuracy tradeoff. Numerous studies have found that words with high ND are named more slowly than those with low ND (Luce & Pisoni, 1998; Vitevitch & Luce, 1998). In turn, participants may require more time to identify a word with high versus low ND due to its similarity with many other forms. Perhaps response latency in the present study led to greater accuracy for recognition of words with high ND. This possibility can be explored further by measuring reaction times in this context.

3.3.3 Error analysis: further evidence of a high ND advantage. In addition to repetition effects of ND, one of the central purposes of this experiment was to examine the nature of errors following misperceptions. Results indicated that participants were more likely to name words that were higher in ND than the target word. This was true for target words with low *and* high ND. Thus, even when a word with high ND was misperceived, a participant's repetition tended to be even higher in ND. These findings are consistent with those of German and Newman (2004), who found that participants with word-finding impairment substituted words that are higher in ND than the target word. Perhaps when a word is unknown (or when only partial phonemic detail is available), the substituted form has high levels of activation from

many different neighbors. Alternatively, participants in the present study may have used a sophisticated guessing system where, in the event of uncertainty, substitutions were more likely to resemble other words. This strategy would theoretically increase the chance of approximating a word more accurately versus producing a word that resembles few other words. It could also explain why misperceptions of words with high ND were even higher in ND.

One caveat about this analysis relates to possible effects of word frequency. Prior work has showed that substitution errors tend to be higher in word frequency than target forms (German & Newman, 2004). As well, Vitevitch (2008) cautions that word frequency may be correlated with ND (but only during the initial stages of lexical acquisition). In order to address this possibility, a post-hoc analysis was conducted comparing the word frequencies of targets with those of substitutions (Vaden & Halpin, 2005). No difference was found, $t(90) = 0.15$, $p > .05$. Thus, although substitutions were higher in ND, they did not significantly differ in terms of word frequency.

3.3.4 Academic implications. In addition to theoretical implications, academic implications likewise exist for the present study. Consider first that speech spectrum-shaped noise was used in the present experiment, which is a realistic type of noise occurring in normal environments, including school classrooms (Crandell, 1991). Current findings revealed that words with high ND were more accurately repeated than those with low ND. Put a different way, words that do not phonologically resemble many other words in the lexicon are not repeated as accurately as those that

do. This discrepancy may become important when considering classroom environments in schools and universities. When teaching subject areas that require auditory models and repetition, certain words may need better presentation. Otherwise, an individual's phonological representation and first productions of a word may be incorrect.

3.3.5 Study limitations. While the current experiment offers insight into the influence of ND during repetition, two limitations should be noted. First, given the relatively difficulty of the task (participants generally scored between 30-40% for overall accuracy), it would be informative to assess repetition in higher accuracy contexts. Perhaps effects of ND would be reduced, or alternatively, even greater. Second, given that reaction times were not measured, it is difficult to test the potential of a speed-accuracy tradeoff. Words with low ND may have had faster response times than words with high ND (as shown previously, Vitevitch & Luce, 1999), subsequently leading to a decrease in accuracy.

3.3.6 Summary. The present study found an advantage for repetition of words that are high as opposed to low in ND. Moreover, when misperceptions occurred, the nature of the error tended to be higher in ND than the target. Results of this experiment implicate that words with many phonologically similar forms can facilitate repetition of one another. This suggests a facilitory nature of the lexicon and is consistent with prior work on speech production (Vitevitch, 1997, 2002), yet contrary to previous studies involving perception (Luce & Pisoni, 1998; Cluff & Luce, 1990).

3.3.7 Future directions. Further investigation is warranted to determine if effects of ND on repetition are similar across development (preschoolers, adolescents), populations (typical, clinical), and languages (e.g., Spanish). For instance, current work in Spanish has yielded conflicting effects of ND. Vitevitch and Rodriguez (2005) reported an inhibitory effect of ND, while Baus, Costa, and Carreiras (2008) found a facilitory effect. It is important to explore the extent to which influences of ND may be universal or language-specific. Additionally, it would be worthwhile to explore how using different definitions of ND can affect the outcome of a study. Given the conflicting findings of past and present experiments (e.g., Luce & Pisoni, 1998), the manner in which phonological similarity is defined is a critical variable to consider. Finally, it would be informative to explore effects of ND on repetition in a more naturalistic setting, such as in classrooms or activity centers. This would help determine the robustness of ND in the presence of more realistic distractions, such as perturbations of pitch and noise in the surrounding environment.

CHAPTER 4

Experiment 3:

Influence of neighborhood density on word learning

4.0 EXPERIMENT INTRODUCTION

Thus far, the current program of research has investigated effects of ND during two tasks: naming (Chapter 2) and repetition (Chapter 3). Given the nature of each task, it was not appropriate for children and adults to serve as participants in both studies. Considering that conflicting effects of ND have been reported across the lifespan (Newman & German, 2002; Vitevitch et al., 2004; Storkel et al., 2006), a critical gap in the research is a study on ND with both children and adults on the same task.

Certain aspects of the lexicon, such as overall size, may affect how a variable such as ND impacts production. This might also account for some of the inconsistencies reported in previous studies. For example, there may be greater amounts of facilitation in the adult versus child lexicon, thereby leading to an advantage for words with high ND for adults (Storkel et al., 2006). Thus, it is possible that children do not benefit similarly (Heisler, 2004; Maekawa & Storkel, 2006).

Additionally, although tasks of naming and repetition can offer insight into the production of *known* words, it is uncertain how ND influences the acquisition of *novel* words. Although lexical acquisition is typically discussed in the context of child language development, adults continue to encounter new words throughout the lifespan as well (e.g., field-specific terms, slang). Hence, any studies of word learning should include children and adults. The following chapter explores this issue in depth.

4.0.1 ND in action: from the beginning. While ND has been researched across numerous tasks of perception and production (Vitevitch & Luce, 1998, 1999;

Newman & German, 2002, 2005; Luce & Pisoni, 1998), it has rarely been examined in the context of learning novel words. Aside from understanding how the phonological similarity of a form can affect tasks such as naming and repetition, it is important to determine if ND affects production from the *initial* stages of word learning. Note that tasks of repetition and naming generally assume prior knowledge of a word: A known word is either named or repeated following an auditory model. This raises the question, what happens when a new word is encountered? Rapid interactions must occur between cognitive mechanisms of memory and semantic association. As well, novel phonological representations must be created. In light of the inconsistencies in findings across prior studies of ND, it may be that differences between tasks may alter how ND affects speech production. Since word learning is arguably a more complex process than simply naming or repeating a word, it is therefore critical to explore influences of ND in such a context. It is possible that using a greater number of cognitive resources could exacerbate an effect of ND. By using a word-learning task, we can gain insight into the extent to which effects of ND apply, and, notably, how even the initial stages of acquisition of a word may be affected by its phonological similarity to other words in the lexicon.

4.0.2 Previous work. Two experiments to date have explored influences of ND on word learning. Recall that Storkel et al. (2006) found that adults learned more words with high as opposed to low ND. However, PP was also a main variable of interest in the study. As a result, stimuli differing in ND were unmatched for PP. This is problematic considering that PP has repeatedly been shown to affect word learning

(Storkel & Rogers, 2000; Storkel, 2001, 2003). It is therefore difficult to differentiate effects of PP from those of ND. Furthermore, only adult participants were included in Storkel et al.'s study. Perhaps differences in lexicon size and/or quality between children and adults might influence such effects of ND.

Another study pursued just this possibility. As reviewed earlier, Heisler (2004) administered a word-learning task to both children and adults. The opposite result of Storkel et al. (2006) was found: For both age groups, words with low ND were better learned than words with high ND. Still, once again PP was a central variable to the experiment. Consequently, low and high ND stimuli were unmatched for PP.

A crucial difference between the two experiments by Storkel et al. (2006) and Heisler (2004) relates to the experimental design. While Storkel et al. analyzed accuracy, Heisler examined variability (in addition to accuracy). Prior to and following the learning phase, Heisler asked participants to repeat target nonwords 15 times following a model; repetitions were thus a critical part of the design. Importantly, when repetitions and spontaneous productions were analyzed separately, effects of ND disappeared for children.

In light of these confounding variables, it is currently unclear how ND influences child and adult word learning, if at all. By examining effects of ND alone during word learning across development, we can better understand the interactive nature of the lexicon during acquisition. Currently, it is uncertain how items in the lexicon affect the learning of a novel word. Existing entries may either serve as competitors or facilitators to the novel form (or neither). This might depend on the

similarity of the phonological form being taught compared to other existing lexical items. If existing entries act as competitors, an advantage should be observed for learning novel words with low versus high ND. Since words with low ND have fewer neighbors, there would be less competition relative to novel words with high ND. Alternatively, if words in the lexicon act as facilitators to a novel word, an advantage for novel words with high ND should be observed, given the greater amount of facilitation.

4.0.3 The present experiment. Given that two previous studies reported contrasting findings for ND during word learning (Storkel et al., 2006; Heisler, 2004), there is reason to assume that ND does impact the degree to which novel words are learned; nevertheless, the direction of such an effect may have been confounded in past research by other influential factors, as stated (e.g., PP, stage of development). The current study was designed to offer clarification on this issue by examining the speech productions of children and adults during a word-learning task. Importantly, novel stimuli must differ only in ND to avoid other influences. Additionally, the current task will measure word acquisition during early and late stages of learning (e.g., following 1 and 4 exposures, respectively). By examining different stages of learning, we can infer how ND operates throughout the learning process. For example, Storkel et al. (2006) reported an effect of ND, but only in the latter stages of learning. This type of knowledge would be useful, for example, when incorporating such a variable in clinical treatment (e.g., children with language impairment). If ND only

impacts later stages of learning, clinicians could have a reasonable expectation for when productive changes might be observed for a newly taught word.

In addition to exploring how ND can affect word learning, the current experiment will also consider the nature of production errors. While a novel form is being acquired, it is presently unknown whether the ND of a real-word substitution may be lower, higher, or similar in ND relative to the target. Consider that German and Newman (2004) reported that when individuals were unable to name a word, their substituted forms tended to be higher in ND (German & Newman, 2004). Nonetheless, no study has pursued this possibility in the context of word learning. If real-word substitutions are higher in ND than the target forms, this would reveal a facilitory influence of the lexicon. Words with multiple neighbors may have greater overall activation during learning, thereby being produced more often in lieu of novel targets. Alternatively, if lexical competition exists in the lexicon, words with low rather than high ND might be substituted during novel word acquisition.

Lastly, previous studies have reported that the magnitude of a related variable, PP, correlates with vocabulary size (Storkel, 2001). That is, the greater the child's vocabulary size, the greater the impact that PP has on her word learning. A comparable effect of ND has yet to be explored. If vocabulary size correlates with effects of ND during word learning, a larger vocabulary should result in greater influences of ND. This might also indicate that children and adults treat ND differently, considering that adults have nearly twice as many items in the lexicon (Templin, 1957; Goulden, Nation, & Read, 1990). In summary, the specific goal of

this experiment was to manipulate the ND of novel words in a word-learning task, to assess whether words are best learned when they contain lower or higher ND, as well as to examine the nature of errors and the potential of correlating effects.

Findings from this study may also offer clinical implications, such as which forms to target for goals of increasing expressive vocabulary. For instance, words with low or high ND might be more easily acquired by children with language impairment. Clinicians could either target such words during treatment or, using a complexity-based approach (Thompson et al., 2003; Stanczak et al., 2006), target the more difficult condition. Nevertheless, if no effects of ND are found during word learning, we would still benefit from this information. Other factors may prove to better aid lexical acquisition (e.g., PP, word frequency).

4.0.4 Predictions. The influence of ND on word learning in children and adults has yet to be explored using the same novel words and narrative. If an effect of ND is found in the present study, it will be important to determine which stages of word learning are impacted. If ND affects learning during all stages (early, late), this would suggest that items in the lexicon would determine the ease with which new words are added. Yet, if an effect is only found during the latter stages of word learning (e.g., following 4 exposures), as was shown by Storkel et al. (2006), this would indicate that other variables may be more influential during initial exposures to a word, such as PP.

Although it is possible that children and adults may treat ND differently during learning, it is predicted they will be affected similarly. This is based on findings from

existing literature. Specifically, prior research has revealed that children produce more words with high versus low ND at earlier ages (Storkel, 2004). This appears to indicate a preference for producing words with high over low ND. As well, Storkel et al. (2006) reported that adults more accurately learned words with high rather than low ND. Finally, according to Vitevitch (2008), preferential attachment in the lexicon should result in greater learning of words with high versus low ND. Recall that this constraint increases the likelihood of adding a word to the lexicon if it has many other neighbors. Under this assumption, words with high ND should best facilitate the acquisition of a novel word. Novel words with high ND may capitalize on increased levels of activation from highly-connected neighbors. If this result is found, we will discover a facilitative influence of the lexicon during word acquisition. Instead of competing with one another, lexical entries might aid in the acquisition of a word. The greater the number of aiding entries (i.e., neighbors), the more accurately a word is acquired. In summary, consistent with findings from previous studies of word learning and assumptions of graph theory, it is predicted that children and adults in the current experiment will learn more words with high versus low ND.

Alternatively, children and adults in the current experiment may learn more words with low versus high ND. Findings from perceptual studies have revealed an inhibitory effect of ND due to lexical competition constraints (Vitevitch & Luce, 1998, 1999; Luce & Pisoni, 1998). As such, novel words with low ND might be perceived to a greater degree than those with high ND. Increased perceptual accuracy could result in better productive learning. As well, Coady and Aslin (2003) found that

children possess sparser neighborhoods than adults (i.e., they have fewer similarly-sounding words). It is possible then that children might prefer words that are phonologically dissimilar to one another.

If children and adults learn (and retain) more words with high versus low ND, lexical facilitation would seem to influence word acquisition throughout the lifespan. Words with few phonologically similar forms might require additional exposures in order to receive adequate activation from existing entries. In contrast, if words with low ND are learned most accurately, less competition (from a smaller number of neighbors) may best facilitate the word learning process. Finally, if words with low and high ND are learned to a similar degree, we will understand the role of phonological similarity (or lack thereof) during word learning. In summary, the present study will help clarify the nature of the lexicon during learning as being one of competition, facilitation, or neither.

Aside from determining which words are learned the best, there are other variables of interest in the current study. Turning now to the nature of production errors, it is predicted that children and adults will substitute words that are higher in ND than the target, following from findings of previous research with participants who have word-finding difficulties (German & Newman, 2004). Perhaps words with many neighbors are the first candidates to be selected as incorrect substitutions for a new word. This could be related to activation levels in the lexicon. Still, it is possible that since participants in the present study are of typical development, different findings may emerge. If words that are lower in ND than the target are substituted, this would

implicate an inhibitory influence of ND. Words with few neighbors may be the first candidates named during instances of uncertainty. It is equally possible that substitutions may be similar in ND as the target.

Lastly, given that receptive vocabulary has been shown to correlate with effects of PP (Storkel, 2001), it is predicted that it will also correlate with ND. This stems from the fact that PP and ND are both phonological variables of the lexicon. Whereas PP is a measure of sound(-sequence) frequency, ND indexes sound similarity. Since words with low ND are composed of similar, infrequently-occurring sound sequences, an important correlation exists between PP and ND (Vitevitch et al., 1999). In light of this correlation, similar influences on the lexicon might exist.

4.1 METHODS

4.1.1 Participants. Thirty-nine children (22 females, 17 males) and 46 adults (44 females, 2 males) (n=85) were recruited to participate in the present experiment. The average age of children participating in the study was 4;6 (years; months) (sd = 0;8; range = 3;0-5;11); the average age of adults participating in the study was 22;8 (sd = 2;7; range = 20;5-32;5). Participant characteristics, recruitment methods, and consent procedures are identical to those described in Chapters 2 and 3 for children and adults, respectively. All participants were native speakers of English and reported no history of speech, language, hearing, or cognitive impairment.

Recall from Chapter 2 that the PPVT-III (Dunn & Dunn, 1997), a standardized measure of receptive vocabulary, was administered to all child participants. The mean

standard score for these children was 105 (sd = 10; range = 89-124), indicating that receptive vocabulary was within typical limits. The PPVT-III was also administered to the adults in the present study to ensure that vocabulary was age-appropriate, and to explore the possibility of correlating effects with ND. The mean standard score for these adults in the study was 106 (sd = 10; range = 88-129), verifying that receptive vocabulary was indeed typical.

4.1.2 Stimuli. Eight monosyllabic CVC nonwords (displayed in Table 4.1) were selected as stimuli in the experiment. In order to avoid confusion, nonwords were phonologically dissimilar from one another (Storkel, 2001). Half of the nonwords contained low ND, and the other half contained high ND. ND was defined identically as with Experiments 1 and 2 (in Chapters 2 and 3, respectively), and was calculated with *Webster's New World Dictionary* (Modern Desk Edition, 1979). Since there are no corpora capable of generating full lexical neighborhoods for nonwords, this was necessarily done by hand. Neighborhoods were partially verified though, using the online *Washington University Speech and Hearing Lab Neighborhood Database* (Sommers), which provides an abbreviated number of neighbors for novel words.

Table 4.1 Nonword stimuli by neighborhood density, condition, and semantic property.

<i>Word</i>	<i>Neighborhood Density</i>	<i>Condition</i>	<i>Semantic Group</i>
/nɛp/	7	low	animal
/dek/	22	high	animal
/mug/	5	low	tool
/pot/	23	high	tool
/kib/	5	low	toy
/baɪm/	18	high	toy
/jot/	7	low	vehicle
/gin/	18	high	vehicle

Experimental stimuli were divided at the median value for ND: Words below the median were considered to have low ND, while words above the median value were considered to have high ND. Words with low ND had a mean ND of 6 neighbors (sd = 1.2; range = 5-7), and words with high ND had a mean ND of 20.3 neighbors (sd = 2.6; range = 18-23). A one-way ANOVA confirmed that the difference in ND was significant, $F(1, 6) = 98.45, p < .01$. Additionally, values in ND for low and high conditions were similar to those for the stimuli in Experiments 1 and 2.

In order to control for other sublexical and lexical factors that could influence word learning, the following variables were not significantly different (all $ps > .05$; see Appendix G: Experiment 3 Stimuli Control) between words with low and high ND:

- a) neighborhood frequency (the word frequencies of a word's neighbors),

- b) stress-weighted phonotactic probability (positional segment frequency; biphone frequency),
- c) word length (number of phonemes; number of syllables),
- d) phonological composition (early acquired sound classes, syllable-final consonants), and
- e) duration (described in detail below).

Stimuli were digitally recorded directly to a Roland Edirol R-09 digital recorder at a sampling rate of 44.1 kHz using a high-quality, bidirectional microphone. All stimuli were recorded in a sound-treated booth (IAC Controlled Acoustical Environment) in two different conditions: 1) in isolation, to be used during a baseline repetition task, and 2) in a scripted narrative (see Appendix H: Experiment 3 Narrative). A female native speaker of English, who uses a General American English dialect, read each nonword in isolation at a normal speech rate. All nonwords were read aloud with similar inflection. Due to potential prosodic intonations associated with list-reading, “filler” words were added at the beginning and end of the list. Next, the same speaker, who is a graduate student in speech-language pathology with clinical experience, read a child-friendly narrative within which the nonword stimuli were embedded. Dr. Sonja Pruitt, an expert in child language, proofread the narrative, ensuring that syntax, vocabulary, and length were age-appropriate for child participants.

All stimuli and the narrative were normalized using Adobe© Audition recording software. This procedure adjusted the overall levels so that the peak

amplitudes were similar to one another. Nonwords that were recorded in isolation were then spliced into individual 16-bit WAV files at a sampling rate of 44.1 kHz. A different native speaker of English identified the nonwords in isolation with 100% accuracy, indicating that the recordings were intelligible and of high quality.

In order to ensure that durations were similar between words with low and high ND, stimuli were measured both in isolation and during the narrative. In isolation, words with low ND had a mean duration of 554 milliseconds ($sd = 77$); words with high ND had a mean duration of 603 milliseconds ($sd = 79$). During the narrative, words with low ND had a mean duration of 512 milliseconds ($sd = 73$); words with high ND had a mean duration of 518 milliseconds ($sd = 66$). Differences in duration between conditions were not significant, $F(1,38) = 0.39, p = .53$.

Next, semantic information was assigned to each nonword by randomly pairing it with a picture of a novel visual object. Objects were designated to one of four semantic categories: tools, animals, toys, or vehicles. Each category contained one nonword with low ND, and one with high ND. In other words, there were two tools presented in the narrative (one with low ND, one with high ND), two animals (one with low ND, high ND), and so on. Pictures of visual objects were piloted to five native speakers of English, who were unable to name the objects with one word. Given that certain objects might be more visually salient (e.g., color, familiarity), pairing of nonword stimuli was counterbalanced across two versions of the narrative. For example, a particular vehicle was associated with low ND nonwords in one

version, and high ND nonwords in the other version. All other aspects remained identical between narrative versions.

There were two episodes in the narrative. The first two visual scenes and accompanying narrative introduced the participants to two main characters and a central problem (i.e., a ship was stranded on an island). In subsequent scenes, characters were depicted interacting with the novel visual objects while the narrative simultaneously presented target nonwords. Two visual objects never appeared in the same scene in order to avoid confusion. Nonwords in each semantic pair were always presented in sentence-final position following identical syntactic constructions, and were counterbalanced for presentation (first, second). For example, participants heard “Maybe a *moog!*” by one character labeling a tool with a low ND nonwords label, followed by a scene with the other character labeling “Maybe a *pote!*” for a tool with a high ND nonwords label. The final two scenes provided a resolution to the story (i.e., fixing the ship and sailing away) in order to provide narrative cohesion.

Since one of the goals in the current study was to investigate how ND influences word learning at different stages, exposure to the nonwords gradually increased during the task. Before the narrative began, a baseline repetition task was administered in which participants repeated each nonword. Thus, one auditory exposure for each nonword was initially presented. This served to examine any potential influences of ND prior to assignment of semantic information. Following the baseline task, one full exposure was provided per nonword during Episode 1, and three additional exposures were provided during Episode 2. Thus, all participants heard a

total of four exposures per nonword, consistent with procedures of Storkel et al. (2006).

In order to assess learning of the nonwords, a picture-naming task was administered following Episodes 1 and 2. During the task, visual objects from the narrative appeared one at a time and participants were asked to name them. Participants were strongly encouraged to guess if they were unsure of a target, given that production errors were also of interest. Probe items were randomized and did not appear in the same order during subsequent testing. Lastly, retention was tested via the same task 10 minutes following the second probe. In summary, overall learning was tested at four points in time: following 1 auditory exposure (prior to semantic assignment), following 1 exposure with semantic assignment (Episode 1), following 4 exposures (Episode 2), and 10 minutes post-exposure.

4.1.3 Design and procedure. The study employed a within-subjects 2x3 factorial design with ND (low, high) and time (1, 4, retention) serving as the independent variables, and production accuracy as the dependent variable. All participants attended one experimental session and were tested individually.

Participants were seated at a laptop computer, which presented auditory stimuli with Microsoft PowerPoint over Sony MDR-7506 headphones at a comfortable listening level. A high-quality, bidirectional microphone was positioned in close proximity to a participant's lips. First, the repetition task was administered. Participants were told that they would be hearing some made-up words and asked to repeat them as quickly and accurately as possible. A practice item was provided to

ensure task comprehension. After each nonword was presented, participants had exactly 3 seconds to repeat the item (Vitevitch & Luce, 1999). Otherwise, the next item was automatically presented and a “no response” was scored. Limiting the amount of time a participant could respond was necessary in order to reduce the influence of cognitive processes (e.g., reasoning by naming a phonologically similar real word).

Following completion of the repetition task, participants were told that they would be hearing a story. Visual pictures and the auditory narrative for Episodes 1 and 2 were presented with Microsoft PowerPoint. Child participants who demonstrated attentional drift during the narrative (i.e., looking away from the screen) were redirected to the story; adult participants needed no such feedback. A picture-naming probe was administered after Episode 1 (e.g., “Do you remember what this was called in the story?”). Participants were then presented with Episode 2 and a subsequent picture-naming probe. After finishing the second probe, participants were given a 10-minute distracter task of identifying pictures (PPVT-III; Dunn & Dunn, 1997). A final picture-naming probe was administered in order to assess retention of the stimuli.

4.1.4 Speech sample recording, transcription, and reliability. All single-word speech samples were digitally recorded directly to a Roland Edirol R-09 digital recorder at a sampling rate of 44.1 kHz. Speech samples were backed up on compact discs and stored in a separate, locked cabinet in a research space at San Diego State University.

All responses were phonetically transcribed by the investigator, a native English speaker and a speech-language pathologist trained in English phonetics and phonology. Inter-rater transcription reliability was calculated for approximately 15% of speech samples by a research assistant trained in English phonetic transcription. Mean point-to-point transcription agreement reached 93% between listeners for children (sd = 6%; range = 87%-100%), and 98% for adults (sd = 4%; range = 87%-100%).

4.1.5 Data analysis. The dependent variables of interest were production accuracy and difference in ND between targets and substitutions. Receptive vocabulary scores were also evaluated in a correlation analysis. Considering that previous studies reported conflicting findings for children and adults (e.g., low ND > high ND, Heisler, 2004; high ND > low ND, Storkel et al., 2006), the two groups were analyzed separately.

Production accuracy was measured with two dependent variables: binary production accuracy and segmental production accuracy. The binary measure of production accuracy was described in detail in Experiments 1 and 2. Considering the difficulty of the present task, this analysis was only appropriate for adult data (only two children produced a completely correct response). If all phonetic segments in a response matched the nonword target, a response was scored as correct. Otherwise, for sound additions, deletions, or substitutions, or if a participant did not produce a valid response (e.g., “I don’t know”), responses were marked as incorrect. Real-word substitutions were also marked as incorrect but noted for another analysis (described

below). Dialectal variations and/or sound distortions (e.g., dental lisps) were not penalized.

A second analysis, which included data from both children and adults, examined segmental production accuracy. The scoring method outlined in Chapter 2 was used (Edwards et al., 2004). Since each CVC nonword in the task had a total of three phonemes, participants could be awarded a maximum of nine points per production (3 phonemes X 3 points per phoneme). In the event of segmental errors, points were deducted accordingly.

In addition to production accuracy, the nature of an error was also of interest. If participants provided a real word for an object, the ND of the substitution was calculated with a database of 33,432 words (Vaden & Halpin, 2005), when such data was available. Semantic approximations were excluded from the analysis. For example, if a child produced “motorcycle” for one of the target vehicles or “hammer” for a target tool, this type of response was likely more influenced by the semantic nature of an object rather than its phonological composition. Thus, only non-semantic related substitutions were considered. In the analysis, the ND of the target was compared to the ND of the substitution. This allowed for a determination of whether productions were lower or higher in ND than target nonword forms (German & Newman, 2004).

Finally, in order to consider if a correlation existed for word learning between effects of ND and vocabulary size, raw scores on the PPVT-III (Dunn & Dunn, 1997) were tallied for all participants. Difference scores were then calculated between rates

of accuracy on the task for each condition. For example, if a participant produced low ND nonwords with 82% accuracy, and high ND nonwords with 67% accuracy, the difference score was noted as 15. Absolute values were warranted, given that, as will be shown, individual participants varied in the directional effect of ND (low ND > high ND, high ND > low ND). Hence, if the above example were reversed (67% and 82% accuracy rates, respectively), the same difference score was calculated (15).

Inter-rater reliability was calculated for scoring on approximately 15% of speech samples by a research assistant trained in phonetic transcription of English. Mean scoring reliability was 94% for children (sd = 5%; range = 86%-100%), and 99% for adults (sd = 2%; range = 94%-100%).

4.2 RESULTS

In order to analyze the data, each participant's production accuracy was averaged across condition (low ND, high ND). Means and standard deviations are displayed in Table 4.3 by age, condition, and point in time. A separate analysis of individual means revealed that approximately 96% of child participants and 100% of adult participants performed similarly to their respective age group (i.e., within two standard deviations of the mean). Accuracy scores were converted to a proportion score and then examined as a function of condition. Proportions were arcsine-transformed to approximate a normal distribution. The transformed data were then submitted to statistical analyses by condition. Consistent with earlier studies of this nature (Heisler, 2004; Storkel et al., 2006), an alpha level of .05 was used for all

statistical tests. Results will be presented for children and adults separately.

4.2.1 Binary production accuracy analysis. The first analysis, conducted only with adult data, explored effects of ND using a binary measure. Accuracy scores (yes, no) were calculated for participants in each condition (low ND, high ND) and at each point in time (baseline, 1, 4, retention). Baseline productions were analyzed using a one-way ANOVA with ND serving as the independent variable, and accuracy the dependent variable. Productions during/after word learning were analyzed in a 2 (ND) X 3 (time) repeated-measures ANOVA with binary production accuracy as the dependent variable (across all three points in time), and ND (low, high) serving as the independent variable.

Average binary production accuracy rates are provided in Table 4.2 by condition and point in time. At baseline, a main effect of ND was found, $F(1,90) = 26.81, p < .01$. Nonwords with high ND were repeated with greater accuracy than those with low ND. Regarding actual learning, no effect of ND was found, $F(1,90) = 0.26, p = .61$. Adults learned words with low and high ND to a similar degree. Not surprisingly, there was a significant effect of time, $F(2,180) = 41.52, p < .01$. Post hoc analysis using Fisher's LSD procedure indicated that accuracy was greater following four exposures and during retention than after one exposure. There was no significant interaction between time and ND, $F(2,180) = 0.17, p = .85$. Therefore, ND did not differently impact early and later stages of word learning. Figures 4.1 and 4.2 illustrate mean percentage accuracy by condition and time.

Table 4.2 Mean binary production accuracy rates and standard deviations for adult word learning by condition and point in time.

	<i>Baseline</i>	<i>1 Exposure</i>	<i>4 Exposures</i>	<i>Retention</i>
Low ND	83.70 (17.65)	19.29 (30.30)	29.89 (23.30)	31.52 (26.58)
High ND	97.83 (7.12)	24.47 (30.40)	33.70 (28.49)	32.24 (31.78)

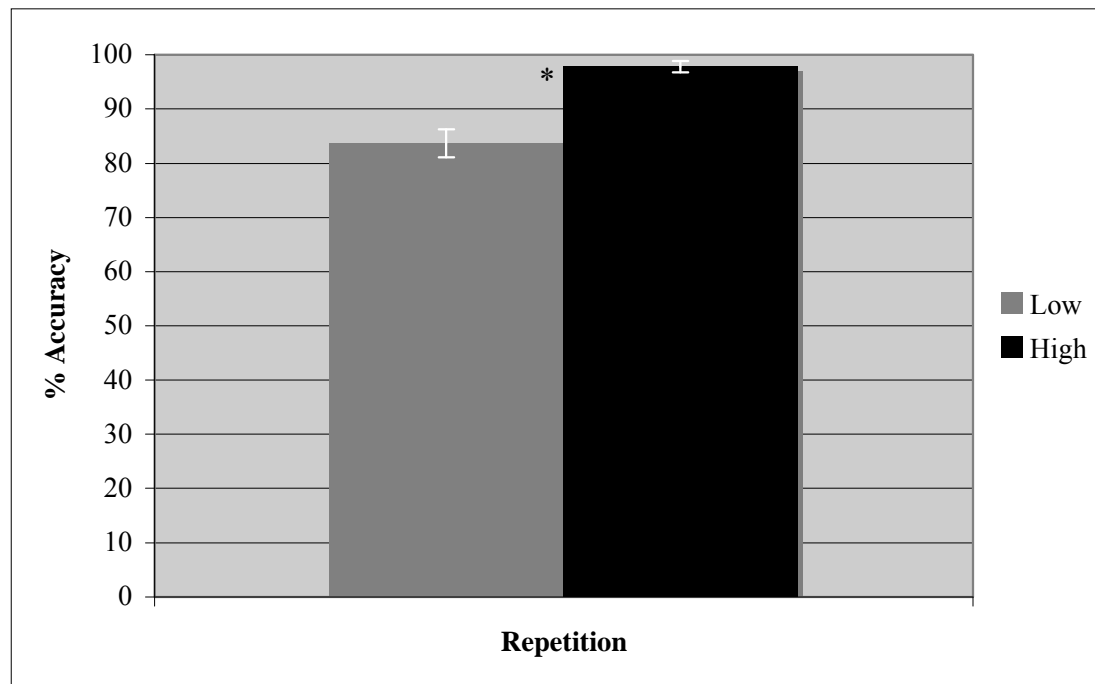


Figure 4.1 Mean binary production accuracy for nonwords at baseline by condition.

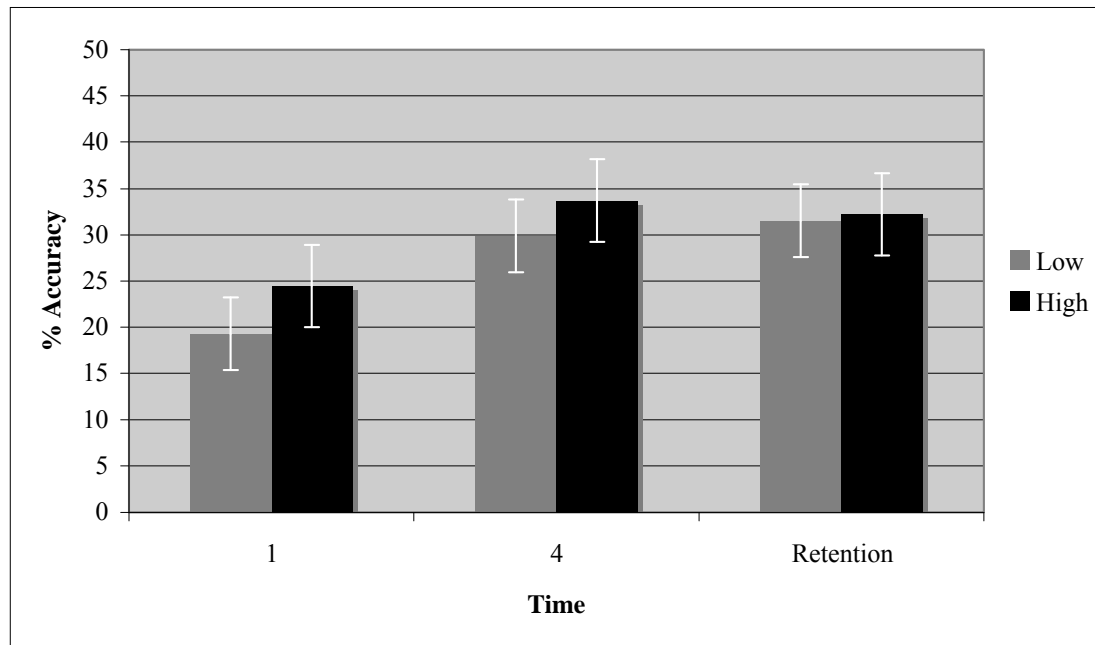


Figure 4.2 Mean binary production accuracy for adult word learning by condition and time.

4.2.2 Segmental production accuracy analysis. The next analysis evaluated segmental accuracy during word learning. Accuracy scores were tallied for participants in each age group (children, adults), condition (low ND, high ND), and point in time (baseline, 1, 4, retention). Productions at baseline were analyzed in a one-way ANOVA with accuracy designated as the dependent variable, and ND the independent variable. During and after word learning, productions were analyzed in 2 (ND) X 3 (time) repeated-measures ANOVAs with segmental production accuracy serving as the dependent variables (across all three points in time), and ND (low, high) serving as the independent variable.

Table 4.3 Mean segmental production accuracy rates and standard deviations for word learning by age, condition, and point in time.

	<i>Baseline</i>	<i>1 Exposure</i>	<i>4 Exposures</i>	<i>Retention</i>
Children				
Low ND	93.73 (6.23)	8.74 (12.86)	23.04 (15.27)	22.94 (16.37)
High ND	96.40 (3.98)	7.40 (10.84)	19.44 (14.19)	12.75 (16.37)
Adults				
Low ND	97.71 (2.64)	43.60 (20.12)	66.85 (21.10)	65.70 (21.34)
High ND	99.76 (0.79)	45.29 (21.30)	64.01 (22.82)	68.78 (19.48)

Results will be presented for children first. At baseline, children more accurately repeated words with high versus low ND, $F(1,76) = 4.93, p = .03$. In order to examine influences of ND on actual learning, children who were less than 5% accurate on overall segmental detail (achieving 10 points or less out of a total of 216) were excluded from the analysis. This left a remainder of 27 child participants, a sample size that is comparable (or even greater) than existing work of this nature (Heisler, 2004; Storkel et al., 2006). A main effect of ND was found, $F(1,52) = 5.38, p = .02$. Contrary to predictions, words with low ND were better learned than those with high ND. A significant effect of time was also found, $F(2,104) = 20.92, p < .01$. Post hoc analysis using Fisher's LSD procedure revealed that accuracy increased between one and four exposures, as well as between one exposure and retention testing. Finally, there was a significant interaction of time and ND, $F(2,104) = 4.50, p = .01$. Words with low ND were learned to a greater degree following four exposures and during retention compared to the first exposure; words with high ND, in contrast, did not show any significant differences over time.

Turning now to adult participants, at baseline, words with high ND were repeated with greater segmental accuracy than those with low ND, $F(1,90) = 28.01$, $p < .01$. There was no effect of ND during and after word learning, $F(1,90) = 0.09$, $p = .77$, although there was a main effect of time, $F(2,180) = 72.95$, $p < .01$. Post hoc analysis using Fisher's LSD method revealed that production accuracy increased from one to four exposures, as well as from one exposure to retention. The interaction of time and ND was not significant, $F(2,180) = 0.85$, $p = .43$. Figures 4.3 and 4.4 illustrate segmental production accuracy by age, point in time, and condition.

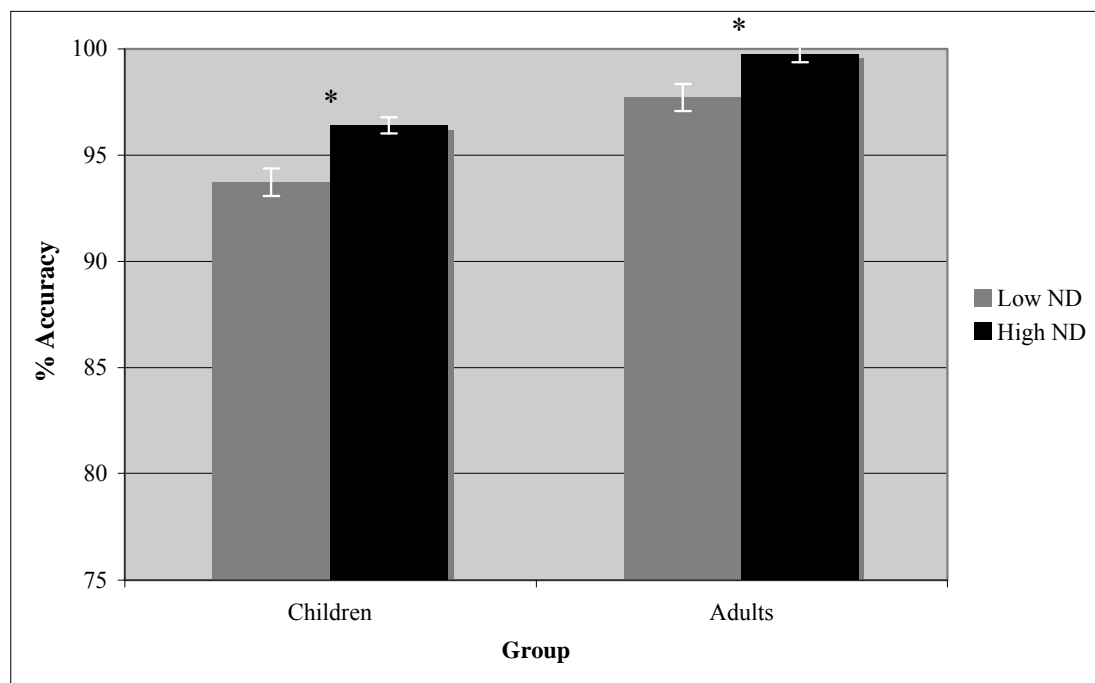


Figure 4.3 Mean segmental production accuracy for nonwords at baseline by age and condition.

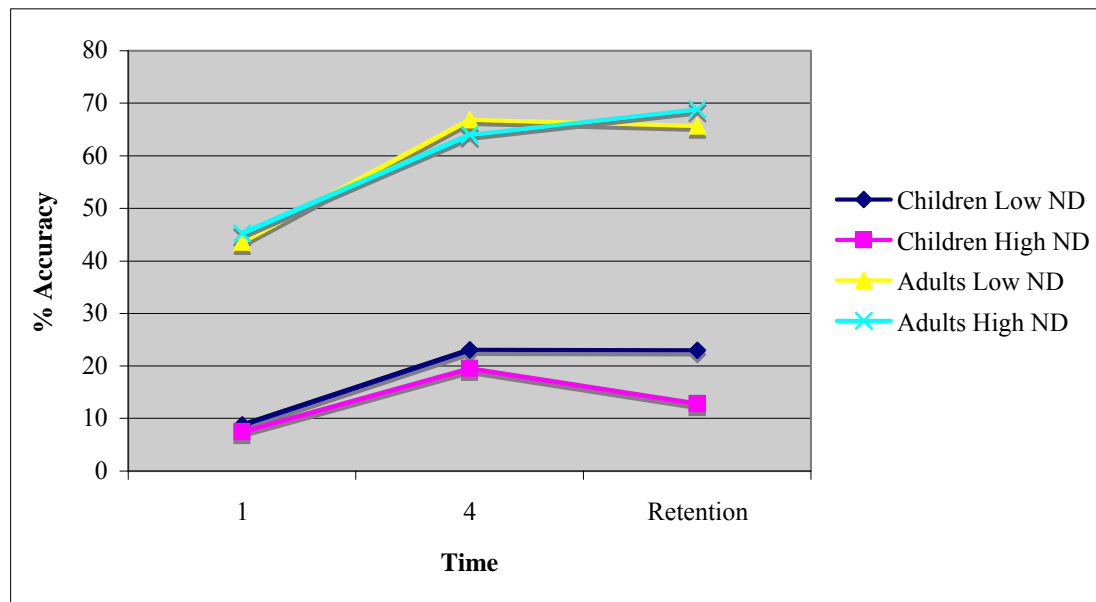


Figure 4.4 Mean segmental production accuracy for word learning by age, condition, and time.

4.2.3 ND comparison. A third analysis compared the ND of target nonwords with those of real-word substitution errors (e.g., [mud] for /mug/). Differences in ND between targets and errors were calculated for both children and adults. Data were submitted to one-way ANOVAs where type of ND (target, substitution) served as the independent variable, and ND the dependent variable.

The mean ND for targets and substitutions are displayed in Table 4.4 by age. For children, the difference in ND was significant, $F(1,50) = 78.36, p < .01$. When target nonwords were substituted with phonologically similar real words, the ND of these forms tended to be higher. The difference in ND was similar for adults, $F(1,74) = 26.43, p < .01$. Real-word substitutions were significantly higher in ND than the target. Figure 4.5 depicts the mean differences in ND between targets and real-word substitutions.

Table 4.4 Means and standard deviations of neighborhood density for word learning by response type and age.

	<i>Target Words</i>	<i>Substitutions</i>
Children	11.72 (5.08)	38.47 (14.54)
Adults	14.40 (4.63)	23.41 (9.76)

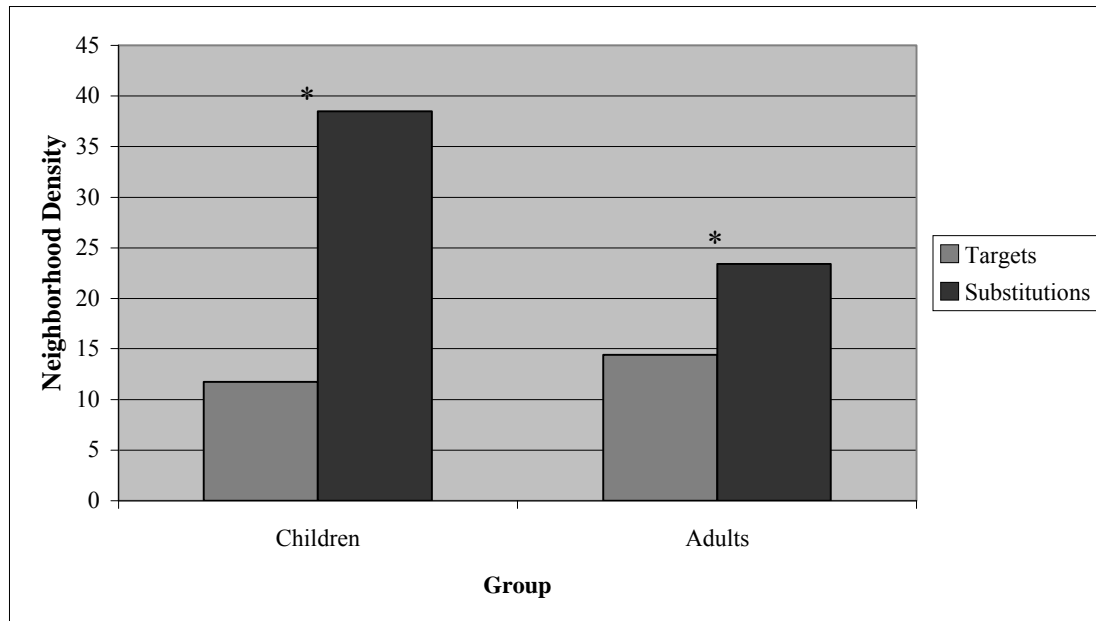


Figure 4.5 Comparison of neighborhood density between targets and substitutions during word learning by age.

4.2.4 Correlation analysis. Finally, in order to investigate if effects of ND correlated with vocabulary size, analyses were completed using Pearson's correlation coefficient method. Participants' raw scores on the PPVT-III (Dunn & Dunn, 1997) were compared to differences in accuracy between words with low and high ND. For both age groups, there were no correlations, all $r_s > .10$, all $p_s > .05$.

4.2.5 Summary of results. Children and adults repeated novel words with high ND more accurately than those with low ND. This effect was not found during

word learning, however. Adults learned words with low and high ND to a similar degree, while children learned words with low ND best. Additionally, when a novel word was incorrectly named, children and adults tended to substitute real words that were higher in ND. Finally, receptive vocabulary was not correlated with effects of ND during learning.

4.3 DISCUSSION

The goal of the present experiment was to determine how existing items in the lexicon interact with the acquisition of nonwords: competitively, facilitatively, or neither. Prior studies of this nature have yielded conflicting results (Storkel et al., 2006; Heisler, 2004); however, ND has typically been investigated in tandem with another variable, PP. Therefore, the current study, which controlled for a variety of factors (including PP), may be the first to investigate a pure effect of ND on word learning in children and adults. This information can expand our understanding of the lexicon as well as increase our knowledge of which variables affect word learning. Such insight can be valuable for clinical populations with vocabulary deficits, for example children with language impairment. In addition, the nature of real-word substitutions was examined to determine how ND might impact production during word acquisition. Lastly, the possibility that effects of ND might correlate with receptive vocabulary was considered. This was an important analysis to conduct to evaluate whether participants with small vocabularies might not benefit as much from influences of ND. Results will first be discussed for the baseline repetition element of

the task, followed by the learning components (1 and 4 exposures, retention). The substitution and correlation analyses will then be addressed.

4.3.1 Baseline: high ND > low ND. In order to assess the initial production status of a word prior to assignment of semantic information, a baseline repetition task was administered. Despite differences in lexicon size, children and adults appeared to treat ND similarly. Both groups repeated nonwords with high ND more accurately than those with low ND, suggesting items in the lexicon *facilitate* repetition of a nonword. Perhaps when a novel word is presented, instead of entries competing with one another for repetition, they aid in its production; thus, words with many neighbors would receive the highest levels of such facilitation. This may have led to the observed greater accuracy on words with high ND at baseline. Although the current finding conflicts with previous work (Luce & Pisoni, 1998; Heisler, 2004), these prior studies failed to control for other influential factors such as PP. Therefore, the present study may be one of the first to examine sole influences of ND on nonword repetition.

Graph theory (Vitevitch, 2008) appears to be capable of accounting for the above results. Recall that words with high ND in the lexicon are structured in larger islands compared to those with low ND. This allows for the possibility that a larger number of forms can facilitate production of a nonword with high versus low ND. If a novel target is phonologically similar to many items in the lexicon, a greater amount of activation can be generated for its target phonemes. Neighbors of such words might provide fast, accurate input during the initial exposure of a word. In contrast, learners might require exposure to more exemplars of nonwords with low ND in order to

achieve similar levels of activation. Results from prior work on processing support this notion: Vitevitch and Luce (1999) found that nonwords with high ND were more quickly named than those with low ND. It seems then that a similar advantage extends to production accuracy.

4.3.2 Developmental differences: ND during learning. Although children and adults demonstrated similar baseline effects of ND, learning performance differentiated the two groups. Adults in the current study learned words in each condition (low ND, high ND) to a similar degree, contrary to previous work (Storkel et al., 2006; Heisler, 2004). This result was consistent at each point in time. Hence, items in the lexicon did not appear to act as competitors *or* facilitators for a novel word. Rather, adults appeared to be unaffected by the experimental manipulation. Children, in contrast, were affected by it. Specifically, children learned words with low ND better than those with high ND. This finding was most evident in the latter stages of learning (following 4 exposures), supporting previous work that ND may not be influential during the earliest stages of word acquisition (Storkel et al., 2006). Lexical competition may account for this better performance on words with low ND. Nevertheless, this would not explain the initial advantage for words with high ND during repetition. This discrepancy is explored in depth next.

Based on the current results, children and adults treat ND differently from one another during novel word learning. Aspects of vocabulary size might be relevant, given that the adult lexicon is nearly twice as large as a developing lexicon (Templin, 1957; Goulden et al., 1990). This quantitative difference could have influenced how

ND affected learning. Perhaps larger lexicons are not (as) affected by lexical competition during word learning. Likewise, the nature of a system that has acquired 17,000+ words (Goulden et al., 1990) is worth considering. Adults possess an impressive toolbox of considerable memory capacity, speech production mastery, and conscious learning strategies (i.e., mnemonic devices). Children, on the contrary, are in the process of mastering lexical acquisition and may still be developing their word learning abilities; moreover, word learning may remain a relatively tacit process during language acquisition. Perhaps once the lexicon reaches a critical size (e.g., in adulthood), the influence of ND may no longer be discernible.

4.3.3 Children's repetitions vs. learning: opposite effects of ND. While children showed an initial advantage for repeating words with high rather than low ND at baseline, the opposite was found for the learning of these words over time. Is it possible that, as discussed in the introduction to this chapter, effects of ND may be task-dependent? It is possible that lexical competition does not occur during nonword repetition since such forms do not exist in the lexicon. Thus, there may not be any "threat" of competition. Nonetheless, incorporating the same form into the lexicon (via semantic association) *could* result in lexical competition. In other words, despite a high accuracy rate for repeating nonwords with high ND (> 95%), once semantic information is assigned, this could pose as lexical competition for existing words. Associating semantic information to a high ND nonword makes the nonword more "wordlike", which in turn might delay its acquisition relative to low ND nonwords. If this is true, then novel words that are phonologically similar to few other existing

forms would have less competition. Novel words with low ND might then be learned sooner than words with high ND. This may explain the contrasting findings of repetition and learning.

Future research is warranted to determine under which circumstances ND facilitates or inhibits production, as it appears its effect may be task-dependent. This may explain the multitude of conflicting findings for ND (Luce & Pisoni, 1998; Storkel et al., 2006; Vitevitch et al., 2004; Newman & German, 2002, 2005). One possibility is related to lexicality. A word's lexical status (nonword, word) may determine the extent to which ND influences perception and production. For example, in Vitevitch and Luce's (1999) perceptual task, they found that adults responded to words with low ND more quickly than to those with high ND; conversely, adults responded to *nonwords* with low ND more *slowly* than those with high ND. Such effects of lexicality may also be relevant for production.

4.3.4 Challenges to graph theory. Recall that Vitevitch (2008) proposed the notion of preferential attachment for the lexicon. According to this constraint, new words are more likely to be added to the lexicon if they can connect highly with other words. Words with high ND should best be learned under this mechanism. This result was not found in the current study. In fact, the opposite was found for children. Considering additional predictions of graph theory, Vitevitch (2008) proposed the existence of empty, uncommitted nodes. He hypothesized that such nodes can become partially activated by novel phonological information, yet still remain uncommitted. Vitevitch predicts these types of nodes are the first to claim novel forms that are

highly similar to other words, thereby affording an advantage to words with high ND. It is possible too though, that competition might arise among partially activated nodes. If so, empty nodes without *any* phonological information could be activated during such a time. This would lead to an advantage for learning words with low versus high ND, since nodes which tend to represent novel words with high ND are competing with one another. Importantly, this would not preclude acquisition of words with high ND, yet merely explain why words with low ND are acquired earlier. Indeed, children in the present study did not increase in production accuracy across exposure for words with high ND. This suggests that a greater number of exposures may be necessary to learn these words. Similarly, Maekawa and Storkel (2006) found that more words with low as compared to high ND are produced at earlier ages.

Although graph theory attempts to account for how ND can affect learning, future models of the lexicon must be able to account for task-dependent findings of ND. Some models that differentiate between early and later cues hold promise in this regard. For example, the emergentist coalition model (ECM; Hirsh-Pasek, Golinkoff, & Hollich, 2000) assumes that a range of cues assist children in learning words; these cues may be differentially available at particular stages of learning. Storkel et al. (2006) argued that ND might initially be an inhibitory cue (low ND > high ND) which gradually becomes more facilitory (high ND > low ND) over the course of development. Since there was no influence of ND for adults in the present study, this cue may cease to influence word learning entirely at some point.

4.3.5 Error analysis: high ND > low ND. Aside from the degree of learning in the present study, another experimental question pertained to the nature of real-word substitutions. Consistent with findings in Chapter 3, real-word substitutions tended to be higher in ND than the target nonwords (e.g., “key” for /kib/). This was true for both children and adults. Although the two groups may have treated ND differently during learning, production errors nevertheless tended to have high ND. As discussed in Chapter 2, this finding may be related to two possibilities. First, children and adults may have been using an implicit, sophisticated guessing strategy. When participants were unable to name a novel word, productions that phonologically match a large number of items would have a greater chance of being accurate. For example, the word *key* has 70 neighbors and was produced for both /gin/ (high ND) and /kib/ (low ND). Substituting real words that are low in ND, in contrast, would reduce the likelihood of matching a target.

The second possibility relates to another lexical factor. ND aside, words that were substituted might also have been high in word frequency. In order to pursue this possibility, word frequencies of real-word substitutions were calculated (Vaden & Halpin, 2005). For children, the average word frequency was 66.97 per million occurrences; for adults, it was 54.48 per million occurrences. Given that high frequency words typically occur over 100 times per million words (Morrisette & Gierut, 2002), it is unlikely that word frequency is responsible for the above effects. In conclusion, real-word substitutions were higher in ND than the target. This suggests a facilitative influence of ND on speech production. Namely, forms with many

neighbors can facilitate speech production during instances of incorrect naming of novel words.

It should be noted that children's real word substitutions were significantly higher in ND than those of adults. The mean ND for children's substitutions was 38, while the mean ND for adults was 23. It therefore appears that children use ND to a greater extent when they are unable to name a target form. It is possible that words with many neighbors may provide greater overall activation for production. Work in the future should determine if this is consistent across other populations, such as with adults with aphasia.

4.3.6 Correlation analysis: receptive vocabulary and ND. Lastly, recall that previous work has found that the magnitude of PP, a phonological variable, correlates positively with the size of the lexicon (Storkel, 2001). In contrast to predictions, no such correlation was found in the present study for ND. As such, children with smaller vocabularies did not seem to treat ND differently than children with larger vocabularies. Adults did not demonstrate a correlation either. Thus, while a sublexical variable like PP may operate in tandem with vocabulary growth, ND does not appear to act similarly. This was somewhat surprising, as one might assume that there would be even more lexical facilitation (or competition) for larger lexicons. Perhaps, though, the effect of sound frequency in a language (i.e., PP) increases with vocabulary growth, whereas ND may correlate with other aspects of language acquisition (e.g., phonological development).

4.3.7 Clinical implications. Since children in the present study learned words with low ND best, clinical populations may also benefit from such forms. For example, children with language impairment might acquire words with low versus high ND more easily due to less competition among lexical items. Treatment goals of increasing expressive vocabulary could target words with low ND. These forms might be learned more quickly than those with high ND, as well as allow for greater generalization outside of a clinical setting. An alternative viewpoint involves theories of complexity (Stanczak et al., 2006; Thompson et al., 2003). Perhaps words with high ND, which were less accurately learned in the present study, may facilitate learning of words with low *and* high ND. This should be addressed in future research.

An interesting population to further examine would be children with phonological impairment (PI). Studies in the past have found that words with high ND result in the least productive sound change following treatment, potentially due to phonological confusion along the lines of lexical competition (Gierut et al., 1999; Morrisette & Gierut, 2002). It is presently unknown whether children with PI might demonstrate a similar disadvantage during word acquisition. Words with low ND may be more quickly acquired than those with high ND. It is also possible that effects of ND could be smaller, too. Munson, Edwards, and Beckman (2005) reported that children with PI exhibited a smaller effect of PP, a related variable, than children with typical language development. They interpreted this unexpected result to suggest that children with PI have poor articulatory and auditory representations of lexical and phonological forms. Hence, there is no greater benefit of nonwords with high PP that

would facilitate generalization to novel contexts. Perhaps the same is true for a variable like ND given its relevance to phonological detail. Studies in the future should explore this area further.

4.3.8 Study limitations. Despite an effort to control for a variety of confounding factors, there are some limitations to the present study. Given the relative complexity of the task, it is difficult to extract where learning might have occurred for some children. Twelve children specifically were unable to learn any of the words, regardless of condition. It would have been informative to offer phonological cues. For instance, when a child was unable to recall a target novel word, the initial phonological segment could have been provided (e.g., /g/ for /gin/). Such cues might have revealed even greater accuracy for words with low ND or, alternatively, remove any observed differences between conditions. It is not expected that such phonological cues would affect the adult population, who learned both kinds of words to a similar degree.

A second limitation relates to the age of the child participants and their stage of development. Unlike adults, this group was not literate. It remains possible that orthographic influences (e.g., spelling) may have altered effects of ND during word learning for adults, despite the absence of written cues in any part of the task. In conclusion, the present findings must not be generalized to all children, but rather to a developmental age group of preschoolers with typical language development.

4.3.9 Summary. The current study found a main effect of ND during repetition in both children and adults, and an effect of ND during children's word learning. At

baseline, novel words with high ND were repeated more accurately than those with low ND. This revealed a facilitory influence of the lexicon during nonword repetition. Once semantic association occurred, however, children learned more words with low versus high ND, suggesting an inhibitory influence of ND on word learning. Items in the lexicon appear to act as competitors to a novel word. Additionally, a facilitory advantage of ND was revealed during an error analysis, where real-word substitutions tended to be higher in ND than the target forms. Finally, no support was found for a correlation between vocabulary size and effects of ND during learning.

4.3.10 Future directions. Further investigations of this nature should include clinical populations, such as children with language impairment and phonological deficits. If similar results are found as reported here, ND might be incorporated into treatment. Research should also be conducted with different age groups, such as school-aged children. If ND ceases to influence word learning at a certain point during development, as was suggested here based on the results from the adults, it would be informative to know when this occurs (and why). Finally, given that participants in the present study were native speakers of English, it is unknown whether words with low ND would offer similar advantages to children speaking other languages (e.g., Spanish). In a highly-inflected language like Spanish (relative to English), phonological competition might be more related to morphology. For example, Spanish has more competing segments at the end of words (e.g., *chico* “boy”, *chica* “girl”, *chicos* “boys”) compared to English (Vitevitch & Stamer, 2006). In light of these differences, other issues related to phonological similarity such as the spread of a

neighborhood (e.g., positions in a word in which neighbors can be created) might be relevant.

CHAPTER 5

Discussion

5.0 OVERVIEW

Neighborhood density is an index of phonological similarity that has been shown to influence speech production across a variety of tasks and populations (German & Newman, 2004; Vitevitch, 2002; Newman & German, 2002, 2005; Heisler, 2004; Storkel et al., 2006; Vitevitch et al., 2004). Results of these previous investigations, however, have often conflicted with one another with regards to exactly how ND influences speech production. Specifically, three possibilities have been found: 1) an *inhibitory* effect of ND, suggesting that lexical items compete with one another (low ND > high ND; Newman & German, 2002); 2) a *facilitory* effect of ND due to aided activation (high ND > low ND; Storkel et al., 2006); or 3) a *null* effect (low ND = high ND; Vitevitch et al., 2004). These conflicting findings may be attributed to uncontrolled parameters of the stimuli (e.g., PP, neighborhood frequency), the nature of a task (e.g., repetition, word learning), and developmental differences (children, adults).

The goal of the foregoing studies was to more thoroughly and carefully explore effects of ND on speech production by administering a series of tasks (naming, repetition, and/or word learning) to typical preschoolers and adults. ND aside, all other factors (e.g., word frequency, PP) were carefully matched between conditions. In addition, the number of neighbors per condition (low, high) was held constant across all three experiments. Elements of speech production that were evaluated included phonological accuracy as well as the lexical nature of error substitutions. These studies were designed to allow us to better understand how entries in lexical neighborhoods

might influence one another during speech production.

It was originally predicted that, based on a recent analysis of the lexicon using graph theory (Vitevitch, 2008), children and adults would more accurately produce words with high versus low ND. A summary of the present results by task and age is provided in Table 5.1.

Table 5.1 Summary of current results.

	Naming	Repetition	Word Learning
Children	low ND < high ND (semantic)		low ND < high ND (baseline)
	low ND = high ND (phonological)		low ND > high ND (learning)
Adults		low ND < high ND (targets)	low ND < high ND (baseline)
		low ND < high ND (errors)	low ND = high ND (learning)

5.0.1 Summary of results. In the first experiment, preschool children were asked to name pictures that corresponded to words with low and high ND. Consistent with predictions, findings revealed that children more accurately named words with high rather than low ND. This was true only according to a semantic analysis, though. When responses were analyzed at the phonological level, no production differences emerged between low and high ND conditions. This result was consistent across several types of analyses, including consideration of segmental features and overall approximations. It appears then that ND does not affect preschool children's production accuracy.

In the second experiment, adults were presented with words over noise and asked to repeat them as quickly and accurately as possible. In line with original predictions, yet in contrast to findings from a plethora of existing studies (Luce & Pisoni, 1998; Benkí, 2003; Cluff & Luce, 1990), adults repeated words with high ND more accurately than those with low ND. This result was found both at the whole-word (i.e., binary accuracy analysis) and the segmental level. It was also discovered that when words were repeated incorrectly, their substitutions tended to be higher in ND than the target. Therefore, an overall advantage was found for words with high as opposed to low ND during adult word repetition.

In the final experiment, children and adults were administered a novel word-learning task. Word learning was measured productively and based on the acquisition of a target's phonological and semantic properties. Eight nonwords (4 with low ND, 4 with high ND) were taught in the context of a narrative. Children and adults performed similarly at baseline, repeating nonwords with high ND more accurately than those with low ND. Regarding learning, children and adults were differently affected by ND. Contrary to predictions, children learned forms with low ND more accurately relative to those with high ND. Adults, in contrast, learned words with low and high ND to a similar degree. In conclusion, children more accurately learned novel words with low versus high ND, while adults learned a word regardless of its ND.

The remainder of this discussion is divided into four major sections. In the next section, methodological factors are considered. Following that, theoretical implications of the findings are presented. In the third section, clinical relevance of the

results is addressed. In the final section, limitations of the current work are considered and directions for future research are proposed.

5.1 METHODOLOGICAL CONSIDERATIONS

The results of this research program are both complementary and contradictory to prior work reviewed in Chapter 1 (German & Newman, 2004; Heisler, 2004; Luce & Pisoni, 1998; Newman & German, 2002, 2005; Storkel et al., 2006). As discussed in Chapters 2, 3, and 4, possible explanations for conflicting results may be due to stimuli classification, confounding variables, and developmental factors. The variable effects of ND on speech production reported in prior research were replicated in the present studies, despite efforts to address the limitations of that prior research. The exact manner in which ND affects the production system seems to depend on several factors, such as the type of task and characteristics of the participants. Consistent with original predictions, items in the lexicon appeared to facilitate one another during some tasks, such as repetition and naming. Nonetheless, lexical competition appeared to exist during other tasks (e.g., word learning). Additionally, although children and adults treated ND similarly in certain contexts, such as during nonword repetition, the two groups responded differently in other tasks, for example word learning. In order to consider how methodological aspects of the current work may have impacted the results, separate discussions will now be provided for the type of task used, the stage of a participant's development, and how ND was defined.

5.1.1 Type of task. Consider first the type of task utilized for evaluated effects of ND. Tasks of naming, repetition, and word learning were administered in the present research program. Notably these tasks differ from one another in a number of ways, such as the amount of perception, visual integration, and semantic association required to respond accurately. Thus, even though speech production was the consistent dependent variable across the three experiments, differing task demands may have impacted the influence of ND.

It was predicted that words with high ND would be named, repeated, and acquired more accurately than forms with low ND. This result was found for both naming and repetition tasks. Given a positive degree of assortative mixing in the lexicon (Vitevitch, 2008), words with many neighbors receive facilitation from multiple activated forms. Such facilitation seems to result in relatively quick and accurate productions, especially under suboptimal circumstances such as confrontational naming for children, and noise-induced repetition for adults. Note that both types of tasks add a level of difficulty and pressure different from natural naming or ideal listening contexts. Perhaps words with low ND require more time or exposures in such situations in order to achieve similar rates of activation as those words with high ND. The assumption is that it may take longer to select words with low ND when time is limited and pressure increased.

While naming and repetition tasks require participants to retrieve or repeat an existing word, word learning arguably is a much more complex process. During word acquisition, participants must recognize a word as being novel upon its presentation,

store its phonological form in working memory, and ultimately assign semantic information to it. In the present work, child participants learned words with low ND more accurately than those with high ND. This suggests an inhibitory effect of ND during learning, such that phonologically similar lexical forms compete with one another for activation. A learner may need additional exposures to a novel word that resembles many items in the lexicon. This might be necessary in order for the lexicon to successfully differentiate such a form from existing items. In contrast, novel words with few existing neighbors have less competition. It is possible that this may have resulted in delayed word learning for words with high ND, thereby affording words with low ND an initial advantage. Note that upon greater amounts of exposure, it is assumed that words with high ND would have been learned successfully. This is a fair assumption considering that, during development, children acquire thousands of words regardless of their ND. Furthermore, children in the present study accurately learned segmental details of novel words with high ND, albeit to a lesser degree than novel words with low ND.

Finally, although both inhibitory and facilitative influences of ND were found, depending on the task, it should be noted that null effects were also discovered. Regarding children's naming accuracy at the phonological level, lexical items did not appear to compete with *or* facilitate one another. Despite conditions differing in ND, children produced words with low and high ND with similar levels of accuracy. This finding is contrary to original predictions of lexical facilitation. Recall that Vitevitch (2008) hypothesized that there would be advantages for acquiring words with high

versus low ND due to more facilitation among neighbors. At the same time, Vitevitch does not distinguish between the semantic and phonological acquisition of a word. This is not uncommon. For instance, the CDI (Fenson et al., 1993), a well-known index of early lexical acquisition, instructs caregivers to score a word as correct if the child produces it in a reasonable capacity (e.g., [po] for “coat”); phonological accuracy is typically ignored, given that very young children are expected to produce some sounds in error. It may therefore be important to consider the possibility that children tend to acquire certain kinds of words before others (e.g., words with low ND, according to Experiment 3). Nevertheless, actual production accuracy remains unaffected by a word’s ND.

5.1.2 Age of participants. In addition to considering the type of task used, it is also important to consider age differences. Preschool children and college-aged adults served as participants in the current research. The size and quality of the lexicons thus differed greatly between the two groups. That is, children’s lexical neighborhoods are sparser than those of adults (Coady & Aslin, 2003). Although the results varied by task, similarities and differences were found between children and adults. First, in the word-learning task, both groups demonstrated a facilitative influence of ND during repetition of novel words. At baseline, children and adults repeated nonwords with high ND more accurately than nonwords with low ND. Hence, for both age groups, lexical items facilitated repetition of novel words. As previously mentioned, according to graph theory, words with many neighbors appear to benefit from increased levels of

activation during repetition (Vitevitch, 2008). Such facilitation seems to be true not only for real words but nonwords as well.

Second, although children and adults treated ND similarly during nonword repetition, the two groups differed while learning (assigning meaning to) the same forms. Adults acquired words with low and high ND to a similar degree. Therefore, it appears that ND did not impact word learning for this group. In contrast, children were affected by the ND manipulation. Specifically, children were more accurate on forms with low ND than those with high ND. Given their smaller lexicons, perhaps children acquire words more easily if they have increased perceptual saliency; this may best signal initial stages of word learning.

Based on the results of the word learning study, children appear to be biased towards learning words with low as opposed to high ND; however, this bias apparently disappears by adulthood. Children may prefer to acquire words with low ND in order to maximize discrimination between words and thereby minimize lexical confusion (Schwartz, 1988). Words with low ND would best serve this goal since such forms do not resemble many other items in the lexicon. Adults on the other hand, who have a much larger vocabulary, have likely mastered such discrimination skills. As such, ND did not affect adult word learning.

5.1.3 How to best define ND. Aside from task demands and participant characteristics, the definition of phonological similarity itself warrants further consideration. Recall from Chapter 1 that ND is traditionally defined as the number of neighbors present in a language by adding, substituting, or deleting a phoneme in any

word position (Vitevitch & Luce, 1998, 1999); this was the definition used for the current research. Although a vast amount of studies of ND over the past decade have used the same definition (Coady & Aslin, 2003; Gierut et al., 1999; Storkel et al., 2006; Newman & German, 2002, 2005; Morrisette & Gierut, 2002; Vitevitch, 2002, 2008; Heisler, 2004), note that earlier experiments defined ND differently. As discussed in Chapter 3, Luce and Pisoni (1998) defined phonological similarity based on the degree of phonetic overlap (i.e., “segmental confusability”). It is possible such a definition is more linguistically motivated, given that ND is supposed to be an index of phonological similarity. For example, consider the words /dɔg/ and /tæg/. While these two words clearly share phonological similarities (e.g., word-initial alveolar stops, word-final voiced velar obstruents), under a traditional one-phoneme metric of ND, /dɔg/ is no more similar to /tæg/ than it is to /fɪʃ/, because they differ by more than one phoneme.

Further investigation is necessary to determine the best manner in which to define phonological similarity. It is possible that at the root of some prior and present inconsistencies lies too broad of a definition of ND. Importantly, a limited definition might pose a problem for issues of universality. If languages differ in what constitutes phonological similarity, perhaps the current findings for English would not generalize crosslinguistically. That is, using a one-phoneme metric might not adequately capture phonological similarity in other languages. For example, tonal systems (e.g., Cantonese) may influence how ND is defined when considering tonal similarity, and highly inflected languages like Spanish might treat ND in conjunction with the spread

of a neighborhood (i.e., positions in a word in which neighbors can be created; Vitevitch & Stamer, 2006). In order to address these concerns, work in the future should explore how phonological similarity can be defined universally (if at all).

In summary, the type of task used, the age of the participant, and the definition of ND may all have factored into the relative effects of ND in the present work. This may also explain the inconsistencies seen across prior investigations of ND (uncontrolled confounds aside). The present work adds to our understanding of the lexicon by learning which tasks are influenced by a word's phonological similarity, and how it affects performance. This helps to clarify the operating nature of the lexicon and how its subcomponents interact depending on the nature of a task. Additionally, by including participants at different ages, it was revealed exactly who might be affected by such influences.

5.2 THEORETICAL CONSIDERATIONS

5.2.1 Revisiting graph theory. The primary goal of this work was to gain insight into how items in lexical neighborhoods interact with one another during speech production: competitively, facilitatively, or neither. Recall that graph theory predicts there should be increased facilitation levels between neighbors due to a high coefficient cluster and positive degree of assortative mixing in the lexicon. Such facilitation could result in a productive advantage for words with high versus low ND. This advantage was observed during children's naming at the semantic level, adult word repetition, and nonword repetition in both groups. Additionally, certain elements

of graph theory, such as the degree of assortative mixing, may also explain why production errors were higher in ND than the target. If words with high ND receive larger amounts of facilitation than those with low ND, these words may be likely substitutes in lieu of production targets. It is also worth noting that while Vitevitch (2008) bases his predictions on a graph of the adult lexicon, a much smaller network (i.e., that of children) appears to operate similarly during repetition and naming.

Turning now to word learning, Vitevitch (2008) predicted that, due to preferential attachment, words with high ND should be more easily acquired than those with low ND. This is based on the assumption that words can be quickly incorporated into the lexicon if they can attach to semi-activated “empty” nodes. These nodes presumably have some phonological information stored and are waiting to be fully activated from highly connected words. Importantly, this prediction was not borne out for either children or adults in the present research program. In fact, children demonstrated the opposite result. Perhaps Vitevitch’s theories of facilitation only apply then during production of known words; items may not facilitate one another during word acquisition. Rather, lexical entries may engage in competition for self-preservation purposes. This seems especially true during early stages of development, since children showed this pattern, but adults did not. In the developing lexicon, instead of entries facilitating the acquisition of a novel word, as originally predicted, lexical items may compete with that novel form if it is similar in phonological composition.

Given that some of the findings from the current study are consistent with predictions of graph theory, certain aspects of the theory may be well-founded. Generally, words with high ND were more accurately produced than those with low ND. This provides support for the assumption that lexical items facilitate one another during production. Note that an inhibitory influence of ND was never observed for adults in any of the tasks. Still, a distinction seems necessary between production of known and novel words. The lexical status of a word may importantly affect how items in the lexicon treat it. This notion is compatible with prior results of processing ND (Vitevitch & Luce, 1999). In summary, it appears that effects of ND cannot be simply classified as inhibitory *or* facilitory. At the same time, it would be misleading to conclude ND plays a little role in speech production; indeed, it appears that ND does affect speech production, but these effects may only be observable under certain conditions.

5.3 CLINICAL IMPLICATIONS

5.3.1 Children with speech-language impairments. In light of task- and age-dependent effects of ND on speech production, incorporating this variable into speech-language treatments should be used with caution and should be based on the target skill of interest. When treating naming deficits in children, for example, words with high ND may be ideal targets. Since words with high ND were more accurately named relative to those with low ND, targeting these words in treatment may lead to earlier success and minimize frustration levels (German & Newman, 2004; German, 2002).

Alternatively, using a complexity approach could be more efficient. By targeting naming of more complex forms, such as words with low ND, overall improvement of the naming system might occur (Kiran & Thompson, 2003). It is possible that this would result in increased naming accuracy for words with low *and* high ND. Future research should pursue this possibility further.

Regarding word learning, results of Experiment 3 (Chapter 4) indicated that typical children acquired words with low ND more easily than those with high ND. If children with language impairment also acquire words with low ND best, this could be applied to treatments of vocabulary deficits. By targeting more words with low versus high ND, expressive vocabulary could be increased in a relatively timely manner. As well, based on the current results, it is likely that words with high ND may require additional exposures for a child to learn them. This information can also guide vocabulary treatment in selecting optimal amounts of exposure.

5.3.2 Adults with language deficits. Given that adults learned words with low and high ND to a similar degree, ND may not be a useful variable to consider when treating adult vocabulary deficits. Based on the present results, the ND of a novel word does not appear to affect adult word learning. Other variables may be more influential instead, such as PP (Storkel et al., 2006).

5.4 LIMITATIONS AND FUTURE DIRECTIONS

5.4.1 Generalizing the findings. There are two main limitations of the current work. First, although children and adults served as participants in the experiments,

performance of the two groups was only comparable for one experiment, word learning. This was due to the age-appropriateness of the tasks. As such, results from Experiments 1 and 2 cannot be generalized across the two populations. This is especially true when considering children and adults did not treat ND similarly during word learning. Perhaps children and adults also differ in other tasks of production. For example, children might repeat words with low and high ND with similar rates of accuracy, unlike adults. Second, while production accuracy was the central variable of interest in all three studies, no other aspects of production were considered, such as kinematic variability, fluency, or duration. Therefore, it remains possible that additional advantages or disadvantages of ND may exist in other areas of production.

5.4.2 Moving forward. The limitations outlined above can help guide future research. First, a series of experiments should be designed that are deemed appropriate for both young children and adults. By comparing the performance of different age groups on the same task, we can better understand why certain aspects of the lexicon (size, quality) may result in differing influences of ND. In addition, working with school-aged populations can help determine the extent to which effects of ND vary across development. Specifically, it will be important to determine when ND ceases to influence word learning. It also remains to be seen why a smaller lexicon would favor acquiring words that are phonologically dissimilar to one another, and yet a developed lexicon shows no preference. As discussed above, children may have a greater need for preserving lexical distinctions during acquisition (Schwartz, 1988). Adults, in contrast, who have lexical neighborhoods higher in ND (Coady & Aslin, 2003), may

no longer have this need. Given a significantly larger vocabulary (nearly double that of a child's), an adult has had many more opportunities to acquire words that are similar to existing items. Such practice may have eliminated this bias toward acquiring lexically distinct forms.

Another important area for future research is to conduct these experiments with clinical populations. In particular, it would be important to administer the word-learning experiment to individuals with language impairment. If results of the current work also extend to clinical populations, this information can be applied to treatment. Another reason for including clinical populations is to examine whether the lexical neighborhoods of clinical populations are organized differently than those of typical populations. This may affect how ND influences speech production and how lexical items interact with one another in general.

Lastly, in order to better understand the observed performance differences between children and adults, a developing lexicon should be analyzed using graph theory. This might inform us of the dynamics that result in an inhibitory influence of ND during children's word learning. It would be interesting to examine, for example, the degree of assortative mixing in a child's lexicon. Words with high ND may not have as many neighbors with similar amounts of connections. Also, it would be important to analyze an impaired network (e.g., aphasia) using graph theory. Components of graph theory may remain the same or, alternatively, change significantly given that atypical development has shown to alter effects of ND (German & Newman, 2004). This could have important clinical relevance.

5.4.3 Conclusions. In summary, the influence of ND on speech production was investigated by examining the productions of children and adults across several tasks. Participants named pictures of words, repeated words in noise, and/or learned novel words varying in ND. Several confounding variables were controlled for in order to isolate any pure influences of ND. Results of this research program confirmed that ND does play a role during speech production; however, the extent and direction of such effects varies greatly, depending on the type of task and the population. The manner in which items in the lexicon interact with one another appears to be based on the type of task, whether or not a word is already known to participants, and the developmental status of the lexicon. Specifically, as compared to words with low ND, words with high ND were more accurately named and repeated by children and adults, yet were acquired to a lesser degree by children. Null effects were also found during children's picture naming at the phonological level. In conclusion, the lexicon appears to be a flexible substrate of language, capable of adapting itself to various circumstances.

APPENDIX

APPENDIX A: Parent Questionnaire for Child Participants.

1. Please list **all** languages your child speaks and age he/she started speaking them. Put "0" if since birth.

Language	Age of Acquisition
<u>English</u>	_____
_____	_____
_____	_____

2. Please list **all** languages your child hears or has heard in the home/school, age they started hearing them (put "0" if since birth), and who speaks them in the home/school.

Language <i>(Home/School)</i>	Age of Acquisition	Who Speaks	Where
<u>English</u>	_____	_____	_____
_____	_____	_____	_____
_____	_____	_____	_____

3. Has your child ever had a head injury or neurological disease that caused any clinical diagnosis of cognitive or speech impairment?

YES NO

If yes, please explain: _____

4. Has your child ever had an accident where he/she lost consciousness?

YES NO

If yes, about how long was your child unconscious? _____

Please explain: _____

- 5.** Does your child have a diagnosed learning disability (for example, dyslexia)?
YES NO

If yes, please explain: _____

-
- 6.** Does your child have/has your child had any speech problems (for example, stuttering)? YES NO

If yes, please explain: _____

-
- 7.** Does your child have/has your child had any hearing impairment?
YES NO

If yes, please explain: _____

Last date of hearing test: _____ Was it normal? YES NO

-
- 8.** Does your child have any uncorrected visual impairments?
YES NO

If yes, please explain: _____

-
- 9.** Is your child taking any medication(s) that might interfere with his/her ability to process pictures or a story and produce responses in this experiment?
YES NO

If yes, please explain: _____

-
- 10.** How well does your child understand what is said to him/her? (circle)

Understands speech all most some none
...of the time

Directions all most some none
...of the time

11. How well can your child be understood by others? (circle)

Parents ...of the time	all	most	some	none
Brothers and sisters ...of the time	all	most	some	none
Child's friends ...of the time	all	most	some	none
Child's teacher ...of the time	all	most	some	none
Other adults ...of the time	all	most	some	none

12. Do you think your child has difficulty with speech or language?

YES NO

If yes, please explain: _____

13. Is your child currently receiving/has your child received intervention for a speech-language impairment?

YES NO

If yes, please explain: _____

14. How would you describe your child's overall coordination? (Circle)

a. Running, skipping, hopping on one foot:

Very good balance Balanced, but sometimes falls Clumsy, falls often

b. Writing with a pencil, coloring within the lines, picking up a penny:

Very precise Good most of the time Sloppy

APPENDIX B: Experiment 1 Stimuli.

Low ND Words	Neighborhood Density	High ND Words	Neighborhood Density
wagon	1	drum	11
guitar	1	water	11
brother	3	feather	12
chicken	3	ladder	13
finger	3	shower	13
flower	4	cloud	14
judge	4	lemon	14
twins	5	teeth	14
queen	7	green	16
brush	8	plate	17
space	8	jeep	20
father	8	vase	21
knife	9	zoo	36
three	9	toes	41
snail	9	nail	42

APPENDIX C: Experiment 1 Stimuli Control.

Variable	Low ND Condition	High ND Condition	Statistic
Word frequency	$M = 106.67 (174.26)$	$M = 58.40 (117.41)$	$F(1,28) = 0.79, p = .38$
Frequency-weighted ND (neighborhood frequency control)	$M = 5.17 (4.35)$	$M = 19.03 (11.82)$	$F(1,28) = 18.14, p < .01$
Positional segment frequency	$M = 0.22 (.07)$	$M = 0.22 (.06)$	$F(1,28) = 0.03, p = .87$
Biphone frequency	$M = .004 (.004)$	$M = .003 (.003)$	$F(1,28) = 0.91, p = .35$
Number of phonemes	$M = 4.07 (.65)$	$M = 3.60 (.74)$	$F(1,28) = 3.15, p = .08$
Number of syllables	$M = 1.47 (.52)$	$M = 1.33 (.49)$	$F(1,28) = 0.53, p = .47$
Imageability	$M = 521.60 (157.96)$	$M = 608.33 (79.06)$	$F(1,17) = 2.20, p = .16$
Familiarity	$M = 365.50 (101.02)$	$M = 377.44 (148.45)$	$F(1,17) = 0.04, p = .84$
Visual complexity	$M = 51.35 (26.85)$	$M = 41.61 (25.35)$	$F(1,28) = 1.04, p = .32$
Age-of-acquisition	$M = 3.94 (2.18)$	$M = 4.04 (1.46)$	$F(1,15) = 0.01, p = .90$

APPENDIX D: Questionnaire for Adult Participants.

1. Which language(s) do you speak? Please list languages and age of acquisition. Put "0" if since birth.

Language	Age of Acquisition
-----------------	---------------------------

<u>English</u> _____	_____
----------------------	-------

_____	_____
-------	-------

_____	_____
-------	-------

2. Have you ever had a head injury or neurological disease that caused any clinical diagnosis of cognitive or speech impairment?
YES NO

If yes, please explain: _____

3. Have you ever had an accident where you lost consciousness?
YES NO

If yes, about how long were you unconscious? _____

Please explain: _____

4. Do you have a learning disability (for example, dyslexia)?
YES NO

If yes, please explain: _____

5. Do you have any speech problems (for example, stuttering)?
YES NO

If yes, please explain: _____

6. Do you have or have you had any hearing impairments?

YES NO

If yes, please explain: _____

7. Do you have any uncorrected visual impairments?

YES NO

If yes, please explain: _____

8. Do you have any kind of memory impairments?

YES NO

If yes, please explain: _____

9. Are you taking any medication(s) that might interfere with your ability to hear stimuli and produce responses in this experiment?

YES NO

If yes, please explain: _____

Please use this space to add any other information that you feel will be helpful to us in understanding your overall development.

APPENDIX E: Experiment 2 Stimuli.

Low ND Words	Neighborhood Density	High ND Words	Neighborhood Density
blind	8	blocks	12
brush	8	bride	24
caused	5	calls	23
charge	7	chest	22
cloth	6	clean	19
coined	7	coast	16
crawl	7	crowd	12
dance	9	dean	42
draw	7	dried	16
ends	5	ears	30
facts	5	failed	22
flesh	9	flight	18
fruit	8	freight	19
grudge	3	grand	15
joined	5	jet	22
lunch	7	luck	27
minds	9	meets	16
mixed	7	missed	25
parked	7	paint	21
plow	9	plays	22
pleased	3	please	14
plus	6	plot	13
proof	3	pride	18
proud	8	prize	16
rev	8	rights	28
scheme	9	scale	13
sharp	6	shares	31
silk	9	sick	43
sky	9	skin	15
slave	5	slight	19
speech	3	speed	13
spoke	9	spite	20
stem	7	stores	15
straw	3	strain	12
task	9	taste	19
tossed	9	tools	16
trend	6	trained	12
trot	6	trip	19
wished	9	waste	15
yarn	6	yard	14

APPENDIX F: Experiment 2 Stimuli Control.

Variable	Low ND Condition	High ND Condition	Statistic
Word frequency	$M = 45.2 (24.19)$	$M = 50.45 (16.11)$	$F(1,78) = 1.31, p = .26$
Frequency-weighted ND (neighborhood frequency control)	$M = 6.39 (2.37)$	$M = 17.93 (7.15)$	$F(1,78) = 94.03, p < .01$
Positional segment frequency	$M = 0.23 (.05)$	$M = 0.23 (.05)$	$F(1,78) = 0.16, p = .69$
Biphone frequency	$M = .003 (.001)$	$M = .003 (.002)$	$F(1,78) = 0.33, p = .56$
Number of phonemes	$M = 4.05 (.50)$	$M = 4.00 (.51)$	$F(1,78) = 0.20, p = .66$
Duration	$M = 670 (102)$	$M = 704 (173)$	$F(1,78) = 1.13, p = .30$

APPENDIX G: Experiment 3 Stimuli Control.

Variable	Low ND Condition	High ND Condition	Statistic
Frequency-weighted ND (neighborhood frequency control)	$M = 9.14 (3.97)$	$M = 31.56 (6.09)$	$F(1,6) = 38.02, p < .01$
Positional segment frequency	$M = 0.11 (.03)$	$M = 0.16 (.03)$	$F(1,6) = 3.28, p = .12$
Biphone frequency	$M = .002 (.002)$	$M = .005 (.003)$	$F(1,6) = 2.37, p = .17$
Duration	Isolation: $M = 554 (77)$ Narrative: $M = 512 (73)$	Isolation: $M = 603 (79)$ Narrative: $M = 518 (66)$	$F(1,38) = 0.39, p = .53$

APPENDIX H: Experiment 3 Narrative.**Version 1***EPISODE 1*

This is a story about two friends: Tyrone and Pablo. Meet Tyrone. Meet Pablo.

Tyrone and Pablo are sailing one day in the ocean. Suddenly they hear a big CRASH and their ship hits an island.

“Oh no!” cries Tyrone. “Our ship is broken. We need something to fix it.”

Pablo thinks for a minute. “Maybe a moog! That should fix it.”

Tyrone thinks for a minute. “Maybe a pote!” That should fix it.”

Pablo says, “Let’s look around the island.” Pablo and Tyrone start walking. Tyrone sees something on the beach. POOF! Out comes a magical genie. “It is your lucky day,” says the genie. “You each get three wishes.” Tyrone says, “I know. We can wish for something that will help us look around the island.”

Tyrone says, “I wish for a geen.” WHOOSH! “Your wish is true,” says the genie. Tyrone is surprised!

Pablo says, “I wish for a yoot.” WHOOSH! “Your wish is true,” says the genie. Pablo is surprised!

“Now if *only* we knew where to look,” says Tyrone.

Pablo says, “Maybe we can find a nepp. I’m sure one must live here. It would know where to look.”

Tyrone says, “Maybe we can find a dake. I’m sure one must live here. It would know where to look.”

Pablo says, “The animals must be hiding. Too bad we don’t have toys for them. Then they might come out. Hey let’s use another wish!”

Tyrone says, “I wish for a bime.” WHOOSH! “Your wish is true,” the genie says. “Wow, thank you!” Tyrone says.

Pablo says, “I wish for a keeb.” WHOOSH! “Your wish is true,” says the genie. “Wow, thank you!” Pablo says. “Now, who’s ready for an adventure?”

EPISODE 2

“I’m ready for an adventure,” says Tyrone. “Me too!” says Pablo.

Pablo looks at his yoot. Pablo gets on his yoot. “I can’t wait to ride on my yoot!”

Tyrone looks at his geen. Tyrone gets on his geen. “I can’t wait to ride on my geen!”

“Ok,” says Pablo, “Let’s race!” Pablo and Tyrone have a fun race. Then they look around.

“Over there!” Tyrone cries. “I see a dake. I knew we would find a dake.” But away runs the dake. “Oh no!” Tyrone says.

“Over there!” Pablo cries. “I see a nepp. I knew we would find a nepp. But away runs the nepp. “Oh no!” Pablo says.

Tyrone says, “Hey, what about our toys?!” Tyrone and Pablo get their toys.

“Cool!” says Pablo. “I can’t wait to play with my keeb.” Pablo picks up the keeb. Pablo says, “It is so much fun playing with a keeb.”

“Cool!” says Tyrone. “I can’t wait to play with my bime.” Tyrone picks up the bime. Tyrone says, “It is so much fun playing with a bime.”

It is starting to get dark. Tyrone sees the sun going down and says, “Uh-oh, it’s getting late. How will we fix our ship?” Pablo thinks for a minute. “Wait! We still have one wish left.”

Tyrone says, “I wish for a pote. I know I can fix the ship with a pote.” WHOOSH!
“Your wish is true,” says the genie. Tyrone picks up the pote. “Thank you genie!”

Pablo says, “I wish for a moog. I know I can fix the ship with a moog.” WHOOSH!
“Your wish is true,” says the genie. Pablo picks up the moog. “Thank you genie!”

Tyrone and Pablo run to the broken ship. They work together. Just before the sun goes down they fix the ship. “We did it! Hip Hip Hooray!”

Pablo and Tyrone start sailing again, excited about their next adventure...

(THE END)

Version 2*EPISODE 1*

This is a story about two friends: Tyrone and Pablo. Meet Tyrone. Meet Pablo.

Tyrone and Pablo are sailing one day in the ocean. Suddenly they hear a big CRASH and their ship hits an island.

“Oh no!” cries Tyrone. “Our ship is broken. We need something to fix it.”

Pablo thinks for a minute. “Maybe a pote! That should fix it.”

Tyrone thinks for a minute. “Maybe a moog!” That should fix it.”

Pablo says, “Let’s look around the island.” Pablo and Tyrone start walking. Tyrone sees something on the beach. POOF! Out comes a magical genie. “It is your lucky day,” says the genie. “You each get three wishes.” Tyrone says, “I know. We can wish for something that will help us look around the island.”

Tyrone says, “I wish for a yoot.” WHOOSH! “Your wish is true,” says the genie. Tyrone is surprised!

Pablo says, “I wish for a geen.” WHOOSH! “Your wish is true,” says the genie. Pablo is surprised!

“Now if *only* we knew where to look,” says Tyrone.

Pablo says, “Maybe we can find a dake. I’m sure one must live here. It would know where to look.”

Tyrone says, “Maybe we can find a nepp. I’m sure one must live here. It would know where to look.”

Pablo says, “The animals must be hiding. Too bad we don’t have toys for them. Then they might come out. Hey let’s use another wish!”

Tyrone says, “I wish for a keeb.” WHOOSH! “Your wish is true,” the genie says. “Wow, thank you!” Tyrone says.

Pablo says, “I wish for a bime.” WHOOSH! “Your wish is true,” says the genie. “Wow, thank you!” Pablo says. “Now, who’s ready for an adventure?”

EPISODE 2

“I’m ready for an adventure,” says Tyrone. “Me too!” says Pablo.

Pablo looks at his geen. Pablo gets on his geen. “I can’t wait to ride on my geen!”

Tyrone looks at his yoot. Tyrone gets on his yoot. “I can’t wait to ride on my yoot!”

“Ok,” says Pablo, “Let’s race!” Pablo and Tyrone have a fun race. Then they look around.

“Over there!” Tyrone cries. “I see a nepp. I knew we would find a nepp.” But away runs the nepp. “Oh no!” Tyrone says.

“Over there!” Pablo cries. “I see a dake. I knew we would find a dake. But away runs the dake. “Oh no!” Pablo says.

Tyrone says, “Hey, what about our toys?!” Tyrone and Pablo get their toys.

“Cool!” says Pablo. “I can’t wait to play with my bime.” Pablo picks up the bime. Pablo says, “It is so much fun playing with a bime.”

“Cool!” says Tyrone. “I can’t wait to play with my keeb.” Tyrone picks up the keeb. Tyrone says, “It is so much fun playing with a keeb.”

It is starting to get dark. Tyrone sees the sun going down and says, “Uh-oh, it’s getting late. How will we fix our ship?” Pablo thinks for a minute. “Wait! We still have one wish left.”

Tyrone says, “I wish for a moog. I know I can fix the ship with a moog.” WHOOSH! “Your wish is true,” says the genie. Tyrone picks up the moog. “Thank you genie!”

Pablo says, “I wish for a pote. I know I can fix the ship with a pote.” WHOOSH! “Your wish is true,” says the genie. Pablo picks up the pote. “Thank you genie!”

Tyrone and Pablo run to the broken ship. They work together. Just before the sun goes down they fix the ship. “We did it! Hip Hip Hooray!”

Pablo and Tyrone start sailing again, excited about their next adventure...

(THE END)

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