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Abstract

The purpose of this tutorial is to underscore the importance of the link between lexical and phonological acquisition by considering learning by children beyond the 50-word stage and by applying cognitive models of spoken word processing to development. Lexical and phonological variables that have been shown to influence perception and production across the lifespan are considered relative to their potential role in learning by pre-school children. The effect of these lexical and phonological variables on perception, production, and learning are discussed in the context of a two-representation connectionist model of spoken word processing. The model appears to offer insights into the complex interaction between the lexicon and phonology and may be useful for clinical diagnosis and treatment of children with functional phonological delays.

The Lexicon and Phonology: Interactions in Acquisition

To acquire the native language, a child must do two things: learn the words of the language and extract the relevant phonological characteristics of these words. For the most part, acquisition of words and sounds has been investigated independently. That is, some lines of investigation concentrate exclusively on how the words of the language are acquired (e.g., Carey & Barlett, 1978; Dollaghan, 1985; Heibeck & Markman, 1987; Jusczyk & Aslin, 1995; Rice & Woodsmall, 1988), whereas other separate lines of research examine how the sounds of the language emerge (e.g., Dinnsen, Chin, Elbert, & Powell, 1990; Dyson, 1988; Smit, Hand, Freilinger, Bernthal, & Bird, 1990; Stoel-Gammon, 1985). The mutual influence of lexical and phonological development is an area that has received only limited attention. The few descriptive and experimental studies that have addressed this issue, however, provide preliminary evidence for an interaction between lexical and phonological development.

Descriptive studies primarily have examined the relationship between the phonological characteristics of babble and first words. Studies of typically developing children have shown that first words are phonologically similar to babble (e.g., Oller, Wieman, Doyle, & Ross, 1976; Stoel-Gammon & Cooper, 1984; Vihman, Ferguson, & Elbert, 1986; Vihman, Macken, Miller, Simmons, & Miller, 1985). For example, the distribution of consonants and the syllable structure of first words are identical to that of babble (Vihman et al., 1985). This association between lexical and phonological development is observed in children with precocious language development as well as those with delayed language development (Paul & Jennings, 1992; Stoel-Gammon & Dale, 1988; Thal, Oroz, & McCaw, 1995; Whitehurst, Smith, Fischel, Arnold, & Lonigan, 1991). In particular, children who know many words tend to produce a greater variety of sounds and sound combinations; whereas, children who know few words tend to produce a limited variety of sounds and sound combinations. There appears to be a potentially robust relationship between the phonological characteristics of first words and babble. This is suggestive of an intimate connection between word learning and productive phonology.

In addition to descriptive evidence, experimental studies provide further support for the hypothesis that lexical and phonological development influence one another. For example, one study of young children with expressive language delay demonstrated that treatment focused on increasing a child's expressive vocabulary led to subsequent improvements in phonological diversity (Girolametto, Pearce, & Weitzman, 1997; but see Whitehurst, Fischel, Lonigan, Valdez-Menchaca, Arnold, & Smith, 1991). This finding suggests that the breadth of a child's lexical knowledge may influence phonological acquisition. An expansion of vocabulary in this case went hand in hand with an expansion of the sound system. In complement, there is experimental evidence that phonological characteristics may influence lexical acquisition. In particular, infants have been shown to produce novel words composed of sounds in their phonetic inventory more frequently than other novel words composed of sounds out of their phonetic inventory (Leonard, Schwartz, Morris, & Chapman, 1981; Schwartz & Leonard, 1982). Here, the child's phonetic inventory influenced acquisition of new words.

Taken together, descriptive and experimental evidence suggests that phonological development and word learning mutually influence one another, but one limitation of this work is its emphasis on infants who produce fewer than 50 words (but see Shillcock & Westermann, 1998; Stoel-Gammon, 1998). This is relevant because a rapid increase in rate of word learning has been noted as children cross the 50-word threshold, leading some to posit a fundamental change in the word learning process (Behrend, 1990; Bloom, 1973; Dore, 1978; Gopnik & Meltzoff, 1986; Mervis & Bertrand, 1994). Also at this point, it is hypothesized that children transition from a holistic to an analytic phonological system, which may demarcate a fundamental change in phonological learning (Ferguson & Farwell, 1975; Vihman, Velleman, & McCune, 1994).

The purpose of this tutorial is to examine this link between lexical and phonological development by considering the acquisition process beyond the 50-word stage and by applying a cognitive model of spoken word perception and production to this issue. In particular, lexical and phonological variables that have been shown to influence perception and production across the lifespan will be considered relative to their potential influence on learning by pre-school children. Furthermore, a model that has been used to explain spoken word processing in the fully-developed system of adults is used to provide a framework for understanding the interaction between the lexicon and phonology in development. The term "spoken word processing" refers collectively to the act of perceiving and producing words in spoken language. The tutorial will be organized to first provide background to the lexical variables of word frequency and neighborhood density and the phonological variable of phonotactic probability. A two-representation model of spoken word processing is introduced. This model depicts two types of mental representations, words versus sounds, providing a means of understanding the interaction between these two different representations. The model is then applied to spoken word processing in the developing system of children and to lexical and phonological learning. Finally, the interaction between the lexicon and phonology will be re-considered by examining the role of lexical variables in sound learning and phonological variables in word learning by pre-school children who have surpassed the 50-word stage. A discussion of the implications of these lexical and phonological variables for clinical diagnosis and treatment will conclude the article.

Background to Lexical and Phonological Variables

Two lexical characteristics that have emerged as relevant predictors of spoken word processing are word frequency and neighborhood density. Considering the first lexical characteristic, word frequency is the number of times a word occurs in the language. For example, "sit" is an infrequent word occurring only 67 times in a written sample of 1 million words. In contrast, "these" is a frequent word occurring 1,573 times in a written sample of 1 million words (Kucera & Francis, 1967).[1] Turning to neighborhood density, words presumably are organized into similarity neighborhoods in the mental lexicon based on phonological similarity. In particular, it is assumed that a similarity neighborhood includes all the words differing from a given word by a one phoneme substitution, deletion, or addition (Luce & Pisoni, 1998). For example, neighbors of “sit” include words such as “sip, sat, hit, it, spit” and neighbors of “these” include words such as “those, tease, ease.” The number of neighbors defined in this way is the word’s neighborhood density. In total, “sit” has 36 neighbors and “these” has 9 neighbors (Nusbaum, Pisoni, & Davis, 1984). Thus, “sit” is said to reside in a dense neighborhood because it has many neighbors, whereas, “these” is said to reside in a sparse neighborhood because it has relatively few neighbors.

A phonological characteristic that appears influential in spoken word processing is phonotactic probability. One observation that has emerged from studies of language structure is that certain sound patterns are more likely to occur. This likelihood of sound occurrence is termed phonotactic probability. Phonotactic probability generally is determined by counting the words in the language that contain a particular sound or sound pattern as well as the number of times those words occur (see Jusczyk, Luce, & Charles-Luce, 1994; Luce, Goldinger, Auer, & Vitevitch, 2000; Storkel, in press; Storkel & Rogers, 2000; Vitevitch & Luce, 1998; 1999). To illustrate, the sound pattern of “sit” is a common sound sequence in English. The individual sounds (/σ/, /I/, /τ/) frequently occur in their given word positions in many frequent words of the language. For example, word-initial /s/ occurs in the words “seat, safe, said, sat, sun, surge, soon, soot, soap, song, sock, south, soil, size” as well as many other words of the language. In addition, the adjacent sounds in “sit” (/σI/, /Iτ/) frequently occur together in many frequent lexical items. The sound combination /σI/ is found in the words “sing, sip, sick, sin, sill” as well as other English words. In contrast, the sound pattern of “these” is a rare sound sequence, having individual sounds (/Δ/, /ι/, /ζ/) and sound combinations (/Δι/, /ιζ/) that occur in relatively few words of the language. In fact, word initial /Δ/ is found only in the words "this, them, then, thus, their, those, that, their" and the sound combination /Δι/ is not contained in any other words of the language.

Model of Word Processing

The lexical variables of word frequency and neighborhood density and the phonological variable of phonotactic probability reportedly influence adults' perception and production. This influence may be accounted for by a two-representation model of word processing (e.g., Gupta & MacWhinney, 1997; Luce et al., 2000).[2] This model may potentially provide insights into the complex interaction between the lexicon and phonology in development, but the characteristics of the model and its success in capturing spoken word processing by adults will first be considered. An illustration of this model is given in Figure 1 for the word "sit" and Figure 2 for the word "these." The two types of representations in the model are lexical and phonological. The lexical representation corresponds to a word as a whole-unit. In Figures 1 and 2, the lexical representation for the word "sit," /σIτ/ and "these," /Διζ/, is denoted by rectangles. In contrast, the phonological representation corresponds to the individual sounds or sound sequences. In Figures 1 and 2, the phonological representations for the words "sit," /σ/, /I/, and /τ/, and "these," /Δ/, /ι/, and /ζ/, are illustrated by the open circles. The structure of the lexical representation may influence perception and production by adults. Likewise, the characteristics of the phonological representation may play a role in adult spoken word processing. Interactions between lexical and phonological representations may also occur in adult word recognition and production. Each of these issues will be considered in turn.

Lexical Representations

This two-representation model is a connectionist model. One feature of a connectionist model is that representations can be activated. That is, hearing or thinking about a word provides external activation to a lexical representation. For a word to be recognized or produced, the activation of its representation must reach a set activation threshold. An activation threshold refers to the amount of activation that must accumulate for the representation to become available to consciousness. It is at this point that the listener recognizes the word or that the speaker selects the word to be produced. Representations can differ from one another in their resting threshold. The resting threshold refers to the initial level of activation of a representation before further external activation is accrued either by hearing the word or thinking of the word. Past experience with the language has been proposed to alter the resting threshold of lexical representations. Specifically, when a lexical representation is frequently activated for recognition or production, the resting threshold supposedly increases. This provides a mechanism for learning the characteristics of the language, namely word frequency. Thus, words that are frequently recognized or produced presumably will have a higher resting threshold than words that are infrequently recognized or produced. In Figures 1 and 2, resting threshold is depicted by the thickness of the rectangles. Heavier rectangles represent higher resting thresholds; whereas lighter rectangles represent lower resting thresholds. The lexical representation of the frequent word /Διζ/ in Figure 2 has a darker rectangle indicating a higher resting threshold than the lexical representation of the infrequent word /σIτ/ in Figure 1. The implication of this difference in resting threshold for perception or production is that words with higher resting thresholds, frequent words, are already more activated at rest than words with lower resting thresholds, infrequent words. As a result, these frequent words should require less external activation than infrequent words to reach the activation threshold for recognition or production and, thus, recognition or production should be facilitated. In fact, studies of spoken word recognition and production with adults support this claim. Adults recognize frequent words more rapidly and more accurately than infrequent words (Landauer & Streeter, 1973; Luce & Pisoni, 1998) and produce frequent words faster and more accurately than infrequent words (Dell, 1990; Dell & Reich, 1981; Huttenlocher & Kubicek, 1983; Oldfield & Wingfield, 1965; Stemberger & MacWhinney, 1986; Vitevitch, 1997). This influence of experience on resting thresholds also allows for the possibility of individual differences across speakers because the exact resting threshold of a given word may vary from speaker to speaker based on a particular speaker's unique language experience.

Another feature of this two-representation connectionist model is that relationships among words are represented by connections. Connections between words are illustrated by lines in Figures 1 and 2. These connections are important because they allow activation to spread between related words, damping or amplifying the related lexical representation's activation. In this way, related lexical representations can influence the activation of the target lexical representation. The presence of two antagonistic processes, damping versus amplifying, are important in capturing decrements in performance and improvements in performance respectively. Damping activation is depicted in the model by inhibitory connections; whereas amplifying activation is depicted by facilitory connections. An inhibitory connection damps the activation of the connected representation impeding that representation from reaching the activation threshold for recognition or production. In this case, recognition or production of the word would be slower or less accurate. In contrast, a facilitory connection amplifies the activation of the connected representation helping that representation reach the activation threshold for recognition or production. In this case, recognition or production of the word would be faster or more accurate. In Figures 1 and 2, inhibitory connections are depicted by lines terminating in filled circles and facilitory connections are depicted by lines terminating in arrows. Neighborhood membership is depicted by inhibitory connections between related lexical representations. For example, the lexical representation /σIτ/ in Figure 1 has inhibitory connections to the lexical representations of all its neighbors, such as /συτ/, /πIτ/, and /νIτ/. Likewise, the lexical representation /Διζ/ in Figure 2 has inhibitory connections to its neighbors, such as /ΔοΥζ/, and /τιζ/. Note that not all of the neighbors of "sit" and 'these" are displayed in Figures 1 and 2 due to space limitations. For example, "spit" is omitted as a neighbor of "sit."

The strength of these connections also are based on the degree of association between words. Thus, words that are more similar to one another will spread more activation between each other. In Figures 1 and 2, the strength of a connection is depicted by the thickness of the line. Heavier lines indicate stronger associations than lighter lines. Note that connections between lexical representations are all similar in strength as indicated by the uniform thickness of the lines. In Figure 1, the lexical representation /σIτ/ has equally strong connections to /συτ/, /πIτ/, /νIτ/ as well as all of its other neighbors. Similarly, in Figure 2, the lexical representation /Διζ/ has equally strong connections to /ΔοΥζ/, /τιζ/ and all of its other neighbors. Thus, all neighbors of a word are considered equally related to the word. The importance of this architecture for perception and production is that the number of neighbors determines the degree of activation damping for the target word. A word like "sit" that resides in a dense neighborhood will receive inhibition from many more words than a word like "these" that resides in a sparse neighborhood. This leads to greater damping of activation for "sit" relative to "these." As a result, a word from a dense neighborhood will be impeded in reaching the activation threshold for recognition or production. This claim is once again supported by data from studies of word processing in adults. Adults recognize words from dense neighborhoods more slowly and less accurately than words from sparse neighborhoods (Luce & Pisoni, 1998; Luce, Pisoni, & Goldinger, 1990). Likewise, word pairs from dense neighborhoods are produced more slowly than word pairs from sparse neighborhoods (Goldinger & Summers, 1989, but see Vitevitch, 2001a)[3].

Phonological Representations

The second type of representation in the model is the phonological representation. It has been proposed that two aspects of the phonological representation are affected by phonotactic probability: resting threshold and connection strength. Considering first resting threshold, recall that language experience alters resting threshold. As a result, sounds that are commonly encountered in recognition or production will likely have higher resting thresholds than those that are encountered rarely. In

Figure 1, the phonological representation /σ/, /I/, and /τ/, has darker circles indicating a higher resting threshold because these sounds commonly occur in the language. In contrast, in Figure 2, the phonological representation /Δ/, /ι/, and /ζ/,[4] has lighter circles indicating a lower resting threshold because these sounds rarely occur. This difference in resting threshold indicates that common sounds are more activated at rest than rare sounds. Consequently, common sounds should reach the activation threshold for recognition or production more rapidly than rare sounds. Turning to connection strength, each sound has a facilitory connection to sounds that it may co-occur with, and the strength of these connections may be altered by language experience. When sounds are commonly encountered together in word processing, it is thought that the connection between the two sounds is strengthened. In this way, the model captures how an adult or child would learn the phonotactic probability of the language through experience. In Figure 1, the phonological representation /σ/ has a strong facilitory connection to that of /I/ because these sounds commonly occur together in words of the language. In contrast, in Figure 2, the phonological representation of /Δ/ has a weak facilitory connection to that of /ι/, because these rarely occur together. Since the strength of the facilitory connection determines how much activation will spread to the related sound, sound sequences with strong facilitory connections, namely common sound sequences, should reach the activation threshold for recognition or production more rapidly than sound sequences with weak facilitory connections, namely rare sound sequences. The influence of phonotactic probability on resting threshold and connection strength leads to the prediction that common sound sequences should be recognized or produced more rapidly than rare sound sequences. Support for this hypothesis is found in studies of spoken word processing by adults. In fact, adults recognize common sound sequences more rapidly than rare sound sequences (Vitevitch & Luce, 1998; 1999; Vitevitch, Luce, Charles-Luce, & Kemmerer, 1997). A similar pattern is observed in speech production, where adults are faster to name a word if it is composed of a common sound sequence rather than a rare sound sequence (Levelt & Wheeldon, 1994).

Interactions between Lexical and Phonological Representations

Turning to the interaction between lexical and phonological representations, it is important to note that there are facilitory connections between lexical and phonological representations. That is, /σIτ/ has facilitory connections to /σ/, /I/, and /τ/; whereas /Διζ/ is connected to /Δ/, /ι/, and /ζ/. The lexical representations of the neighbors of /σIτ/ and /Διζ/ also have connections to phonological representations, but not all of these connections are shown in Figures 1 and 2 because it becomes difficult to follow the connections when all are presented together. For example, /συτ/ should have facilitory connections to /σ/ and /τ/, but these are not displayed in Figure 1. The implication of these lexical-phonological connections is that once a lexical representation is activated, it will also activate its corresponding phonological representation. Activation can also occur in the opposite direction with a phonological representation activating corresponding lexical representations. These connections between lexical and phonological representations allow for interactions between lexical and phonological processing.

One way that the interaction between lexical and phonological representations has been investigated in the fully-developed system of adults is by considering the unique relationship between neighborhood density, a lexical variable, and phonotactic probability, a phonological variable. Namely, words from dense neighborhoods tend to be composed of common sound sequences, and words from sparse neighborhoods tend to be composed of rare sound sequences (Vitevitch, Luce, Pisoni, & Auer, 1999). The evidence detailed in the previous sections indicated that dense neighborhoods slow spoken word processing, whereas, common sound sequences speed word processing. Given the association between neighborhood density and phonotactic probability, the inhibitory effect of neighborhood density and the facilitory effect of phonotactic probability would seem incompatible. If the two factors are associated, how is it that one aids word recognition and production but the other interferes with it? If one appeals to the variable of neighborhood density, one would predict that processing of a word from a dense neighborhood, such as “sit,” would be inhibited relative to a word from a sparse neighborhood, such as “these.” In contrast, if one appeals to the variable of phonotactic probability, one would predict that processing of a word having a common sound sequence, such as “sit,” would be facilitated relative to a word having a rare sound sequence, such as “these.” How can processing of “sit” be both inhibited and facilitated?

This paradox may be resolved by appealing to the two-representation model. If one type of representation is able to dominate word processing in a given context, this will dictate whether an inhibitory or facilitory effect is observed. The lexical status of the stimulus is predicted to influence the effect of neighborhood density and phonotactic probability on processing. In particular, lexical processing is predicted to dominate language tasks involving real words because real words have a lexical representation. In contrast, phonological processing is predicted to dominate language tasks involving nonwords because nonwords have no lexical representation. This prediction is borne out by evidence from studies of spoken word processing by adults. In fact, recognition of real words from dense neighborhoods is inhibited relative to real words from sparse neighborhoods, supporting the dominance of lexical processing (Vitevitch & Luce, 1998; 1999). In complement, recognition of nonwords composed of common sound sequences is facilitated relative to nonwords composed of rare sound sequences, supporting the dominance of phonological processing (Vitevitch & Luce, 1998; 1999). Since spoken word processing typically involves real words, lexical processing generally should dominate recognition and production (but see Vitevitch, 2001b).

Application to Development

The two-representation model seems to successfully capture lexical and phonological influences on perception and production in the fully-developed system of adults. Can this model be applied to perception and production in the developing system of infants and children? Evidence of how the lexicon influences spoken word processing in infants and children is reviewed and compared to the findings from adults to address this question. If the findings from the developing system parallel those from the fully-developed, then the two-representation model may easily be extended to the developing system. In contrast, if word processing in the developing system differs from the fully-developed, then the two-representation model may require modification before application to the developing system. This question is important because it bears on the issue of whether the two-representation model may offer insights into learning and clinical practice.

Studies of the developing language systems provide further insight into the role of word frequency and neighborhood density in spoken word processing. Perception studies with infants have investigated aspects of the spoken input that infants attend to while building the mental lexicon (Jusczyk, 1997 for review). In one representative study of word frequency, infants were exposed to sets of words that were frequently repeated in stories versus other sets of words that were infrequently repeated (Hohne, Jusczyk, & Rendanz, 1994; Jusczyk & Aslin, 1995). Results indicated that infants preferred listening to the frequently occurring words in the story. This finding suggests that infants have the ability to attend to specific words in the input. Moreover, they were able to differentiate words based on their frequency of occurrence. Word frequency has also been shown to influence young children’s production accuracy of target sounds. Leonard and Ritterman (1971) found that 7-year old children had better production accuracy of target /σ/ sounds in frequent versus infrequent words in the language (but see Moore, Burke, & Adams, 1976).

Computational studies of young children have further explored the structure of words in the early lexicon relative to neighborhood density. These studies used receptive and expressive estimates of young children's lexicons. One important finding was that young children have relatively sparse neighborhoods in comparison to older children and adults (Charles-Luce & Luce, 1990, 1995; Logan, 1992). That is, a word in a young child’s lexicon would have fewer neighbors than that same word in an older child’s or an adult’s lexicon. Neighborhood density may increase across the lifespan as more phonetically similar words are added to the lexicon (Logan, 1992). This finding led to the hypothesis that young children use global recognition strategies to identify words (Charles-Luce & Luce, 1990, 1995). Because neighborhoods are so sparse, all of the fine-grained phonetic contrasts of language may not be necessary to uniquely disambiguate one word from another. Alternatively, it has been argued that children do rely on fine-grained recognition strategies (Dollaghan, 1994). The basis for this comes from the fact that young children do differentiate between minimally and phonetically similar words of the input. Even a word that has only one neighbor must still require fine-grained coding on the part of the child for accurate recognition. While these views about whether children use global or fine-grained recognition strategies remain at odds, it is clear that the structure of words in the lexicon appears to be critically linked to the nature of a child's phonological representations. Taken together, these findings support that a word's frequency and its neighborhood density play a similar role in fully-developed and developing lexicons.

In the developing language system, sensitivity to phonotactic probability emerges early with phonotactic probability influencing perception in a manner similar to adults. In perceptual tasks, 9-month old infants listen longer to lists of words composed of common sound sequences than to those composed of rare sound sequences (Jusczyk et al., 1994). Moreover, infants appear to rapidly acquire phonotactic probability in controlled listening conditions (Aslin, Saffran, & Newport, 1998; Saffran, Aslin, & Newport, 1996). After listening to strings of nonsense syllables for a short period of time, 8-month-old infants are able to discriminate syllable sequences that commonly co-occur from those that rarely co-occur. That is, syllables that commonly co-occurred in the speech sample were treated as a whole word; whereas syllables that rarely co-occurred were not treated as a whole word. The evidence indicates that infants may learn the likelihood of occurrence of sound sequences in the ambient language, and then they use this to parse continuous speech into individual words.

Sensitivity to phonotactic probability continues into childhood as shown in metalinguistic, perceptual, and production tasks. In metalinguistic tasks, children and adolescents are able to differentiate sound sequences that are legal in their language from those that are illegal (Messer, 1967; Pertz & Bever, 1975). Children, like adults, seem to have intuitions about phonotactics (e.g., Vitevitch et al., 1997). Perceptual and production studies provide evidence that children are also sensitive to the more fine-grained distinction of common versus rare sound sequences. Relative to perceptual evidence, children rapidly extract the phonotactic probabilities of continuous strings of nonsense syllables. Like infants, children treat strings of syllables that commonly co-occur as an entire word and strings of syllables that rarely co-occur as a part of a word (Saffran, Newport, Aslin, Tunick, & Barrueco, 1997). In production, children are more accurate producing sound sequences that are permissible in the ambient language than those that are not (Messer, 1967). Moreover, children are more accurate repeating common than rare sound sequences (Beckman & Edwards, 1999). Likewise, when given a list of nonwords to remember, children recall more nonwords if the list contains common sound sequences than if it contains rare sound sequences (Gathercole, Frankish, Pickering, & Peaker, 1999). In childhood, sensitivity to phonotactic probability remains and appears to influence spoken word processing in a manner that parallels the fully-developed adult system.

The effects of word frequency, neighborhood density, and phonotactic probability on language perception and production in the developing system parallel those in the fully-developed system. In terms of lexical variables, across the lifespan processing of frequent words was facilitated relative to infrequent words, and processing of words from dense neighborhoods was inhibited relative to words from sparse neighborhoods. In terms of phonological variables, across the lifespan, common sound sequences were recognized and produced more rapidly than rare sound sequences. Given the similarity between the adult and child findings, it appears that the two-representation model can be applied to perception and production by children.

Application to Learning

Because the two-representation model captures perception and production by children, it also may provide insights into learning by children. In the following two sections, insights of the two-representation model for sound change and word learning will be offered and evaluated relative to current findings. The studies reviewed focus on interactions between the lexicon and phonology in pre-school and school-age children who have lexicons with many more than 50 words. These investigations provide evidence of whether lexical-phonological interactions continue in development beyond the 50-word stage.

Promoting Sound Change

When a sound is unknown, the child presumably will have no ambient, or adult-like, phonological representation for the target sound. In some cases, treatment may be needed to promote sound change. The goal of treatment then is to create an ambient phonological representation for the unknown sound, often by presenting the target sound in words and providing feedback regarding production accuracy. Given the absence of an ambient phonological representation, lexical processing is predicted to dominate sound learning in this treatment context. Thus, lexical representations may influence the success of phonological treatment. In particular, treatment of the sound in frequent words should promote sound change relative to infrequent words. Furthermore, embedding the sound in words from dense neighborhoods should inhibit learning when compared to treatment of the sound in words from sparse neighborhoods.

An experimental treatment study by Gierut, Morrisette, and Champion (1999) examined the role of lexical variables in phonological treatment (see also Morrisette & Gierut, 2001). Twelve children with functional phonological delays, aged 3;0 to 7;4, participated in an alternating treatments design to promote sound change. The characteristics of word frequency and neighborhood density were experimentally manipulated. Experimental conditions included treatment of all possible combinations of frequent/infrequent words from dense/sparse neighborhoods. Each child was taught two sounds, affiliated with the lexical characteristics of the assigned conditions. For example, a child assigned to the Frequent versus Infrequent condition was taught one sound in frequent words and another sound in infrequent words. Treated sounds were excluded from the pretreatment inventory and produced with 0% accuracy. Generalization accuracy in production of the treated sounds to untreated words and contexts was measured as the dependent variable and submitted to statistical analysis. Treatment conditions and corresponding results are shown in Table 1.

Results revealed that for the lexical characteristic of word frequency, phonological treatment using frequent words induced significantly greater generalization learning than did treatment of infrequent words. For neighborhood density, treatment in words from sparse neighborhoods induced significantly greater generalization learning than words from dense neighborhoods. When the frequency conditions were compared to the density conditions, treatment in both frequent and infrequent words resulted in significantly greater generalization learning than treatment in words from dense neighborhoods. Further, treatment in frequent and infrequent words resulted in greater or equivalent generalization learning than treatment of words from sparse neighborhoods.

Overall, the characteristic of word frequency was most salient in inducing phonological change as compared to neighborhood density. Moreover, in every comparative condition, frequent words consistently facilitated sound change, whereas words from dense neighborhoods consistently failed to promote generalization learning. These results were replicated by Morrisette and Gierut (2001) and are consistent with the predictions of the two-representation model. Frequent words in the language consistently emerged as facilitating spoken word processing and learning; whereas, words from dense neighborhoods in the language consistently emerged as inhibiting spoken word processing and learning. Moreover, phonological learning by pre-school children was influenced by the lexicon, paralleling previous findings from much younger children.

Novel Word Learning

Applying the two-representation model to novel word learning, a child presumably will have no corresponding lexical representation for a newly encountered word. In the absence of a lexical representation, the two-representation model predicts that phonological processing will be most influential. Thus, phonological processing is hypothesized to influence the creation of a lexical representation for the novel word. Because phonological processing is facilitated for common over rare sound sequences, children should learn novel words composed of common sound sequences more rapidly than those composed of rare sound sequences.

Storkel and Rogers (2000) provide a direct test of this hypothesis that phonotactic probability should influence word learning. Typically developing school-age children from three age groups, age 7, 10, and 11, participated in a nonword learning task, where half of the nonwords were composed of common sound sequences and half were composed of rare sound sequences. The target nonwords were associated with unfamiliar objects. Children were exposed to the nonword-object pairs in a lecture-format, and referent identification was tested immediately following exposure. The results showed a significant interaction between phonotactic probability and age. The two older groups of children learned more common than rare sound sequences; whereas the youngest group of children showed no difference in learning common versus rare sound sequences. This interaction between phonotactic probability and age was not predicted and was further investigated in a second study (Storkel, in press).

In Storkel (in press), word learning by pre-school children was investigated in a multi-trial word learning paradigm. In particular, nonword learning was assessed in several tasks emphasizing either form or referent learning at multiple points in time. Pre-school children were exposed to nonwords: half were composed of common sound sequences and half, rare sound sequences. The nonwords served as names for nonsense objects. The nonword-object pairs were embedded in a story containing multiple story episodes with learning being assessed after each episode. Results showed that across measures of learning and exposures, pre-school children learned more nonwords composed of common than rare sound sequences.

Across the two studies, younger and older children seemed to learn novel words composed of common sound sequences more rapidly than those composed of rare sound sequences, supporting the predictions of the two-representation model. As in language perception and production tasks that are dominated by phonological processing, word learning was facilitated for common sound sequences relative to rare. Phonological characteristics appeared to play a role in word learning by pre-school and school-age children, complementing previous findings with younger children. Phonology appeared to influence lexical development beyond the 50-word stage. Moreover, various aspects of phonology seem to impact development of the lexicon including the child's phonetic inventory and the phonotactic probability of the novel word (Leonard et al., 1981; Schwartz & Leonard, 1982; Storkel, in press; Storkel & Rogers, 2000).

Clinical Implications

The finding of a continued interaction between the lexicon and phonology in children who have surpassed the 50-word threshold has clinical implications for children with functional phonological delays and children with specific language impairment. Children with functional phonological delays reportedly have a primary delay in the acquisition of phonology. Given the evidence documenting an interaction between the lexicon and phonology, lexical characteristics may play a role in promoting sound change. In contrast, children with specific language impairment appear to exhibit delays in lexical acquisition (e.g., Dollaghan, 1987; Oetting, Rice, & Swank, 1995; Rice & Woodsmall, 1988; Rice, Buhr, & Nemeth, 1990). Phonological variables may provide insights in the diagnosis and treatment of delays in word learning.

Children with Functional Phonological Delays

The results of Gierut and colleagues (1999) indicate that lexical variables of target words do appear to influence the process of sound change in treatment for children with functional phonological delays. When children were taught sounds in frequently occurring words, they made significant gains in their production accuracy of the target sound. In contrast, when children were taught sounds in words from dense neighborhoods they failed to learn the treated sound. This suggests that phonological treatment should focus on frequent words in the language, and avoid the use of words from dense neighborhoods. These results have direct clinical implications for the kinds of words that should be selected for phonological treatment.

A sample of treatment words is presented in Table 2 to illustrate. These words were adapted from the Morrisette and Gierut (2001) study and are consistent with procedures for the selection of treatment words in the Gierut et al. (1999) study. In this sample, the target fricative /f/ was taught in the word-initial position of frequent words in the language. Word frequency counts were obtained from Kucera and Francis (1967) and neighborhood density values came from a computational database of 20,000 English words (Nusbaum et al., 1984). Frequency counts and density values are more generally available for clinical use through the online Neighborhood Database at http://www.artsci.wustl.edu/~msommers. Operational definitions for frequent versus infrequent and dense versus sparse neighborhoods were consistent with previous investigations of word frequency in phonological acquisition (e.g., Morrisette, 1999). Frequent words were selected based on a word frequency count greater than 100. Thus, all of the words in Table 2 have a word frequency greater than 100. Further, because a word has both a frequency and density, the words were balanced for neighborhood density. Half of the words came from dense neighborhoods, with 10 or more neighbors, and half of the words came from sparse neighborhoods, with fewer than 10 neighbors.

Following from the Gierut et al. (1999) and Morrisette and Gierut (2001) studies, treated words were pictured on a computer screen and elicited through drill activities. Children attended three one-hour treatment sessions each week and proceeded through two phases of treatment: imitation and spontaneous production. During the imitation phase, the child named the treated words following a clinician's model. Imitation continued until the child achieved 75% production accuracy of the target sound across two consecutive sessions or until seven sessions were completed, whichever came first. During the spontaneous phase, the child named the treated words without a model. This phase continued until the child achieved 90% production accuracy of the target sound across three consecutive sessions or until twelve sessions were completed, whichever came first. Feedback related to the accuracy of the child's production of the target sound was provided during both phases.

Generalization learning for each child was monitored through spontaneous picture naming tasks or probes. These probes were designed to sample the treated sound and other untreated sounds that were excluded from the child's pretreatment sound inventory in untreated words and across contexts. Probes were administered throughout treatment, immediately following treatment and at 2 weeks and 2 months posttreatment. Percentages of accuracy were then calculated and plotted as generalization learning curves. Thus, based on results from Gierut et al. (1999), it is predicted that phonological treatment using the frequent words illustrated in Table 2 would result in generalization of /ϕ/ to untreated words and contexts. Importantly, it should be noted that although half of the frequent words selected were from high density neighborhoods, the consistent variable was word frequency. Treatment programs consisting of words that are all from dense neighborhoods should be avoided. Based on the Gierut et al. (1999) study, treatment in words from dense neighborhoods resulted in minimal or no learning of the treated sound.

Children with Specific Language Impairment

The results of Storkel (in press) suggest that the phonological characteristics of novel words influences lexical acquisition. Thus clinically it may be important to consider phonotactic probability in the diagnosis and treatment of delays in lexical acquisition in children with specific language impairment. These children may have difficulty learning phonotactic probability due to either perceptual processing deficits (Ellis-Weismer & Hesketh, 1996; 1998) or limited lexical exemplars resulting from delays in language acquisition. Children with specific language impairment may fail to show a learning advantage for common over rare sound sequences. In support of this hypothesis, Storkel (in press) reported that increased vocabulary size was correlated with an increased learning advantage for common over rare sound sequences in children with age-appropriate lexical development. Delays in word learning and a decreased effect of phonotactic probability may go hand-in-hand. As a result, it may be necessary to examine the influence of phonotactic probability on word learning in this population. Unfortunately, standardized measures of vocabulary may not be sensitive to the factors that affect word learning because these tests examine the products of learning rather than the process itself. Therefore, clinicians may need to construct tasks that investigate the process of word learning to provide further insights into the factors that contribute to a particular child's poor word learning ability. Here, guidance is provided by past experimental studies that have employed procedures that may be adapted for clinical use. In particular, the procedures used in Storkel (in press) may be appropriate. This multi-trial word learning paradigm was administered individually in one 30-minute session with a follow-up 10-minute session to examine retention. Thus, the time commitment is similar to other standardized test protocols. Moreover, Storkel and Rogers (2000) successfully administered their word learning task to groups of students in a classroom. There are several important steps in constructing a measure of word learning: (1) identifying the stimuli to be learned; (2) exposing the child to the stimuli; (3) measuring learning. Each step will be described in turn.

Identification of the stimuli to be learned involves choosing nonwords or unknown real words and associating these with referents. In Storkel (in press), nonwords were selected as stimuli so that the phonological characteristics could be controlled. Specifically, all nonwords were composed of early acquired consonants that were correctly articulated by the participating children. This guarded against the influence of misarticulation on word learning (Leonard et al., 1981; Schwartz & Leonard, 1982). Half of the nonwords were composed of common sound sequences and half were composed of rare sound sequences. Calculation of phonotactic probability is complex and requires access to a database; however, several published studies provide lists of common versus rare nonwords (e.g., Jusczyk et al., 1994; Storkel, in press; Storkel & Rogers, 2000; Vitevitch & Luce, 1999) or words (e.g., Vitevitch & Luce, 1999). The nonwords used in Storkel (in press) are shown in Table 3. The nonwords were paired with object referents to parallel real words. Novel objects were invented or adapted from published children's stories. Objects were selected in pairs from the same semantic category. Each object from a semantic pair was associated with either a common or a rare sound sequence. In this way, semantic and conceptual factors were similar across the levels of phonotactic probability. A description of the objects is provided in Table 3.

For exposure, the nonword-object pairs were embedded in a story containing three story episodes. Pictures were adapted from children's stories (Mayer, 1993) to show two main characters interacting with one another and with the nonsense objects. Semantically paired objects were shown in the same picture with each being associated with a different main character. A story narrative was created to accompany the story pictures. The narrative is shown in the appendix. Note that the exposure sentences were matched across common and rare sound sequences. For example, in the first episode, the exposure sentence for the common sound sequence /πιν/ is "My favorite is the πιν" and for the rare sound sequence /μ□Iδ/ is "My favorite is the μ□Iδ." This matching of sentences was intended to equate syntactic factors across the levels of phonotactic probability. Another feature of the story narrative was that the number of times the nonwords were repeated varied across the episodes. That is, the children heard each nonword one time in episode 1, but three times in episodes 2 and 3. Given that children with specific language impairment reportedly need more exposures to learn novel words, it may be necessary to increase the number of repetitions of the nonwords for this clinical population. This could be accomplished by revising the story narrative or by having the child listen to the narrative twice.

Storkel (in press) measured learning after each story episode. Three measures of learning were obtained: referent identification, form identification, and picture naming. In the referent identification task, a nonword was presented and the child attempted to select the object from a field of three picture choices that included the target, the semantically related referent, and a semantically unrelated referent presented in the story. For the target nonword /πιν/, the child saw pictures of both candy machines and a picture of one of the pets. In the form identification task, an object was presented and the child attempted to select the nonword from a field of three choices. The choices paralleled those of the referent identification task. For example, the child was shown a picture of one of the candy machines and heard three possible names, /πιν/, /μ□Iδ/, /κoYφ/. As each nonword was played, the investigator pointed to one of three squares. The child then pointed to the square associated with his or her answer. In the picture naming task, an object was presented and the child attempted to produce the nonword. Again the child might see a picture of one of the candy machines but this time be asked to produce the nonword associated with the object with no choices or prompting provided by the investigator.

Following administration of these procedures, proportion correct can then be computed for common versus rare sound sequences at each test point (episode 1, episode 2, episode 3) for each measure of learning (referent identification, form identification, picture naming). Difference scores can then be computed by subtracting proportion correct for rare sound sequences from proportion correct for common sound sequences. If there is an advantage of common over rare sound sequences, the resulting number will be positive. This would parallel the findings for typically developing children (Storkel, in press; Storkel & Rogers, 2000). If there is no difference between common and rare sound sequences, then the resulting number will be zero. If there is a disadvantage of common relative to rare sound sequences, then the resulting number will be negative. In either of these last two cases, the result would differ from those reported for typically developing children. This would suggest that one contributing factor to the child's difficulties with word learning may be difficulty using phonological information to support word learning.

Conclusion

The findings reviewed support the hypothesis that the lexicon and phonology seem to continue to influence one another even after the 50-word threshold has been surpassed. In particular, the relationship in pre-school and school-age children appeared to be bi-directional in nature with the lexicon influencing phonological acquisition and phonology influencing lexical acquisition. The two-representation model of word processing held promise in capturing this relationship. Thus, models of spoken word processing may hold potential for understanding the process of language acquisition. From a clinical perspective, this theoretical model may guide the diagnosis and treatment of phonological or lexical delays in children.

References

Aslin, R. N., Saffran, J. R., & Newport, E. L. (1998). Computation of conditional probability statistics by 8-month-old infants. *Psychological Science*, *9*, 321-324.

Beckman, M. E., & Edwards, J. (1999). Lexical frequency effects on young children's imitative productions. In M. B. Broe & J. B. Pierrehumbert (Eds.), *Papers in laboratory phonology V* (pp. 208-218). Cambridge, MA: Cambridge University Press.

Behrend, D. A. (1990). The development of verb concepts: Children's use of verbs to label familiar and novel events. *Child Development, 61,* 681-696.

Bloom, L. (1973). *One word at a time: The use of single word utterances before syntax*. The Hague: Mouton.

Brown, G. D. (1984). A frequency count of 190,000 words in the London-Lund Corpus of English Conversation. *Beavior Research Methods, Instruments and Computers*, *16*, 502-532.

Carey, S., & Bartlett, E. (1978). Acquiring a single new word. *Papers and Reports on Child Language Development, 15*, 17-29.

Charles-Luce, J., & Luce, P. A. (1990). Similarity neighbourhoods of words in young children's lexicons. *Journal of Child Language, 17*, 205-215.

Charles-Luce, J., & Luce, P. A. (1995). An examination of similarity neighbourhoods in young children's receptive vocabularies. *Journal of Child Language, 22*, 727-735.

DeBrunhoff, L. (1981). *Babar's anniversary album*. New York: Random House.

Dell, G. S. (1990). Effects of frequency and vocabulary type on phonological speech errors. *Language and Cognitive Processes, 5,* 313-349.

Dell, G. S., & Reich, P. A. (1981). Stages in sentence production: An analysis of speech error data. *Journal of Verbal Learning and Verbal Behavior*, *20,* 611-629.

Dinnsen, D. A., Chin, S. B., Elbert, M., & Powell, T. W. (1990). Some constraints on functionally disordered phonologies: Phonetic inventories and phonotactics. *Journal of Speech and Hearing Research, 33,* 28-37.

Dollaghan, C. A. (1985). Child meets word: "Fast mapping" in preschool children. *Journal of Speech and Hearing Research, 28,* 449-454.

Dollaghan, C. A. (1987). Fast mapping in normal and language-impaired children. *Journal of Speech and Hearing Disorders, 52*, 218-222.

Dollaghan, C. A. (1994). Children's phonological neighbourhoods: Half empty or half full? *Journal of Child Language, 21*, 257-272.

Dore, J. (1978). Conditions for the acquisition of speech acts. In I. Markova (Ed.), *The social context of language* (pp. 87-111). New York: Wiley.

Dyson, A. T. (1988). Phonetic inventories of 2- and 3-year-old children. *Journal of Speech and Hearing Disorders, 53*, 89-93.

Ellis Weismer, S., & Hesketh, L. J. (1996). Lexical learning by children with specific language impairment: Effects of linguistic input presented at varying speaking rates. *Journal of Speech and Hearing Research, 39*, 177-190.

Ellis Weismer, S., & Hesketh, L. J. (1998). The impact of emphatic stress on novel word learning by children with specific language impairment. *Journal of Speech, Language, and Hearing Research, 41*, 1444-1458.

Ferguson, C. A., & Farwell, C. B. (1975). Words and sounds in early language acquisition. *Language*, *51*, 419-439.

Gathercole, S. E., Frankish, C. R., Pickering, S. J., & Peaker, S. (1999). Phonotactic influences on short-term memory. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 25*, 84-95.

Gierut, J. A., Morrisette, M. L., & Champion, A. H. (1999). Lexical constraints in phonological acquisition. *Journal of Child Language, 26*, 261-294.

Geisel, T. S., & Geisel, A. S. (1954). *Horton hears a who!* New York: Random House.

Geisel, T. S., & Geisel, A. S. (1958). *Cat in the hat comes back*. New York: Random House.

Girolametto, L., Pearce, P. S., & Weitzman, E. (1997). Effects of lexical intervention on the phonology of late talkers. *Journal of Speech, Language, and Hearing Research, 40*, 338-348.

Goldinger, S. D., & Summers, V. W. (1989). Lexical neighborhoods in speech production: A first report. *In Research on Speech Perception No. 15 (pp. 331-342).* Bloomington, IN: Speech Research Laboratory, Indiana University.

Gopnik, A., & Meltzoff, A. N. (1986). Words, plans, things and locations: Interactions between semantic and cognitive development in the one-word stage. In S. Kuczaj & M. Barrett (Eds.), *The development of word meaning* (pp. 115-151). New York: Springer-Verlag.

Gupta, P., & MacWhinney, B. (1997). Vocabulary acquisition and verbal short-term memory: Computational and neural bases. *Brain and Language, 59*, 267-333.

Heibeck, T. H., & Markman, E. M. (1987). Word learning in children: An examination of fast mapping. *Child Development, 58*, 1021-1034.

Hohne, E. A., Jusczyk, A. M., & Rendanz, N. J. (1994, June). *Do infants remember words from stories*? Paper presented at the meeting of the Acoustical Society of America, Cambridge, MA.

Huttenlocher, J., & Kubicek, L. F. (1983). The source of relatedness effects on naming latency. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 9*, 486-496.

Jusczyk, P. W. (1997). *The discovery of spoken language*. Cambridge, MA: MIT Press.

Jusczyk, P. W., & Aslin, R. N. (1995). Infants' detection of the sound patterns of words in fluent speech. *Cognitive Psychology, 29*, 1-23.

Jusczyk, P. W., Luce, P. A., & Charles-Luce, J. (1994). Infants' sensitivity to phonotactic patterns in the native language. *Journal of Memory and Language, 33,* 630-645.

Kolson, C. J. (1960*). The vocabularies of kindergarten children*. Unpublished dissertation. University of Pittsburgh.

Kucera, H., & Francis, W. N. (1967). *Computational analysis of present-day American English*. Providence, RI: Brown University.

Landauer, T. K., & Streeter, L. A. (1973). Structural differences between common and rare words: Failure of equivalence assumptions for theories of word recognition. *Journal of Verbal Learning and Verbal Behavior*, *12,* 119-131.

Leonard, L. B., & Ritterman, S. I. (1971). Articulation of /s/ as a function of cluster and word frequency of occurrence. *Journal of Speech and Hearing Research, 14,* 476-485.

Leonard, L. B., Schwartz, R. G., Morris, B., & Chapman, K. (1981). Factors influencing early lexical acquisition: Lexical orientation and phonological composition. *Child Development, 52*, 882-887.

Levelt, W. J., & Wheeldon, L. (1994). Do speakers have access to a mental syllabary? *Cognition, 50*, 239-269.

Logan, J. S. (1992). *A computational analysis of young children's lexicons.* (Research on Spoken Language Processing Technical Report No. 8). Bloomington, IN: Speech Research Laboratory, Indiana University.

Luce, P. A., Goldinger, S. D., Auer, E. T., & Vitevitch, M. S. (2000). Phonetic priming , neighborhood activation, and PARSYN. *Perception & Psychophysics, 62*, 615-625.

Luce, P. A., & Pisoni, D. B. (1998). Recognizing spoken words: The neighborhood activation model. *Ear and Hearing, 19,* 1-36.

Luce, P. A., Pisoni, D. B., & Goldinger, S. D. (1990). Similarity neighborhoods of spoken words. In G. T. M. Altmann (Ed.), *Cognitive models of speech processing: Psycholinguistic and computational perspectives*. Cambridge, MA: MIT Press.

MacKay, D. G. (1987). *The organization of perception and action: A theory for language and other cognitive skills*. New York: Springer-Verlag.

Mayer, M. (1992). *Professor wormbog in search for the zipperump-a-zoo*. Italy: Rainbird Press.

Mayer, M. (1993). *Little critter's read-it-yourself storybook: Six funny easy-to-read stories*. New York: Golden Book.

Mervis, C. B., & Bertrand, J. (1994). Acquisition of the novel name nameless category (N3C) principle. *Child Development, 65*, 1646-1663.

Messer, S. (1967). Implicit phonology in children. *Journal of Verbal Learning and Verbal Behavior, 6*, 609-613.

Moore, W. H., Burke, J., & Adams, C. (1976). The effects of stimulability on the articulation of /s/ relative to cluster and word frequency of occurrence. *Journal of Speech and Hearing Research, 19,* 458-466.

Morrisette, M. L. (1999). Lexical charactersitics of sound change. *Clinical Linguistics & Phonetics, 13*, 219-238.

Morrisette, M. L., & Gierut, J. A. (2001). *Effects of word frequency and neighborhood density on phonological treatment*. Manuscript submitted for publication.

Nusbaum, H. C., Pisoni, D. B., & Davis, C. K. (1984). Sizing up the Hoosier mental lexicon. In *Research on Speech Perception No. 10* (pp. 357-376). Bloomington, IN: Speech Research Laboratory, Indiana University.

Oetting, J. B., Rice, M. L., & Swank, L. K. (1995). Quick incidental learning (QUIL) of words by school-age children with and without SLI. *Journal of Speech and Hearing Research, 38*, 434-445.

Oldfield, R. C., & Wingfield, A. (1965). Response latencies in naming objects. *Quarterly Journal of Experimental Psychology, 17*, 273-281.

Oller, D. K., Wieman, L., Doyle, W., & Ross, C. (1976). Infant babbling and speech. *Journal of Child Language, 3*, 1-11.

Paul, R., & Jennings, P. (1992). Phonological behavior in toddlers with slow expressive language development. *Journal of Speech and Hearing Research, 35*, 99-107.

Pertz, D. L., & Bever, T. G. (1975). Sensitivity to phonological universals in children and adolescents. *Language, 51*, 149-162.

Rice, M. L., Buhr, J., & Nemeth, M. (1990). Fast mapping word learning abilities of language delayed preschoolers. *Journal of Speech and Hearing Disorders, 55,* 33-42.

Rice, M. L., & Woodsmall, L. (1988). Lessons from television: Children's word learning when viewing. *Child Development, 59*, 420-429.

Rinsland, H. D. (1945*). A basic vocabulary of elementary school children*. MacMillan: New York.

Saffran, J. R., Aslin, R. N., & Newport, E. L. (1996). Statistical learning by 8-month-old infants. *Science, 274*, 1926-1928.

Saffran, J. R., Newport, E. L., Aslin, R. N., Tunick, R. A., & Barrueco, S. (1997). Incidental language learning: Listening (and learning) out of the corner of your ear. *Psychological Science, 8,* 101-105.

Schwartz, R. G., & Leonard, L. B. (1982). Do children pick and choose? An examination of phonological selection and avoidance in early lexical acquisition. *Journal of Child Language, 9*, 319-336.

Shillcock, R., & Westermann, G. (1998). The role of phonotactic range in the order of acquisition of English consonant. In W. Ziegler & D. Karin (Eds.), *Clinical phonetics and linguistics* (pp. 65-71). London: Whurr Publishers Ltd.

Smit, A. B., Hand, L., Freilinger, J. J., Bernthal, J. E., & Bird, A. (1990). The Iowa articulation norms project and its Nebraska replication. *Journal of Speech and Hearing Disorders, 55*, 779-798.

Stemberger, J. P., & MacWhinney, B. (1986). Frequency and the lexical storage of regularly inflected forms. *Memory and Cognition, 114*, 17-26.

Stoel-Gammon, C. (1985). Phonetic inventories, 15-24 months: A longitudinal study. *Journal of Speech and Hearing Research, 28*, 505-512.

Stoel-Gammon, C. (1998). Sounds and words in early language acquisition: The relationship between lexical and phonological development. In R. P. D. Paul (Ed.), *Exploring the speech-language connection* (Vol. 8, pp. 25-52). Baltimore: Paul H. Brooks Publishing Co.

Stoel-Gammon, C., & Cooper, J. A. (1984). Patterns of early lexical and phonological development. *Journal of Child Language, 11*, 247-271.

Stoel-Gammon, C., & Dale, P. (1988, May). *Aspects of phonological development of linguistically precocious talkers.* Paper presented at the Child Phonology Conference, University of Illinois, Champaign-Urbana.

Storkel, H. L. (in press). Learning new words: Phonotactic probability in language development. *Journal of Speech, Language, and Hearing Research*.

Storkel, H. L., & Rogers, M. A. (2000). The effect of probabilistic phonotactics on lexical acquisition. *Clinical Linguistics & Phonetics, 14*, 407-425.

Thal, D. J., Oroz, M., & McCaw, V. (1995). Phonological and lexical development in normal and late talking toddlers. *Applied Psycholinguistics, 16*, 407-424.

Vihman, M. M., Ferguson, C. A., & Elbert, M. (1986). Phonological development from babbling to speech: Common tendencies and individual differences. *Applied Psycholinguistics, 7*, 3-40.

Vihman, M. M., Macken, M. A., Miller, R., Simmons, H., & Miller, J. (1985). From babbling to speech: A re-assessment of the continuity issue. *Language, 61*, 397-445.

Vihman, M. M., Velleman, S. L., & McCune, L. (1994). How abstract is child phonology? Toward an integration of linguistic and psychological approaches. In M. Yavas (Ed.), *First and second language phonology* (pp. 9-44). San Diego, CA: Singular.

Vitevitch, M. S. (1997). The neighborhood characteristics of malapropisms. *Language and Speech, 40*, 211-228.

Vitevitch, M. S. (2001a). *The influence of phonological similarity neighborhoods on speech production*. Manuscript submitted for publication.

Vitevitch, M. S. (2001b). *When is a word not a word? Facilitative and competitive effects of phonotactic probability on the recognition of spoken words*. Manuscript submitted for publication.

Vitevitch, M. S., & Luce, P. A. (1998). When words compete: Levels of processing in perception of spoken words. *Psychological Science, 9*, 325-329.

Vitevitch, M. S., & Luce, P. L. (1999). Probabilistic phonotactics and neighborhood activation in spoken word recognition. *Journal of Memory of Language, 40*, 374-408.

Vitevitch, M. S., Luce, P. A., Charles-Luce, J., & Kemmerer, D. (1997). Phonotactics and syllable stress: Implications for the processing of spoken nonsense words. *Language and Speech, 40*, 47-62.

Vitevitch, M. S., Luce, P. A., Pisoni, D. B., & Auer, E. T. (1999). Phonotactics, neighborhood activation, and lexical access for spoken words. *Brain and Language, 68*, 306-311.

Whitehurst, G. J., Fischel, J. E., Lonigan, C. J., Valdez-Menchaca, M. C., Arnold, D. S., & Smith, M. (1991). Treatment of early expressive language delay: If, when, and how. *Topics in Language Disorders, 11*, 55-68.

Whitehurst, G. J., Smith, M., Fischel, J. E., Arnold, D. S., & Lonigan, C. J. (1991). The continuity of babble and speech in children with specific expressive language delay. *Journal of Speech and Hearing Research, 34*, 1121-1129.

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Appendix: Storkel (in press) Story Narrative

Episode 1

[Picture 1] Mom and dad were at work. Big brother had to take care of little sister. Little sister was crying. “I’ll take you to the park if you stop crying,” said Big Brother. [Picture 2] “We can go to the candy machines at the park,” said Big Brother. “My favorite is the πιν.” Little Sister said, “My favorite is the μ□Iδ.”[Picture 3] “Can we bring some toys,” asked Little Sister. “Yes,” said Big Brother. “I’m bringing my ναYβ.” Little Sister said, “I’m bringing my ωΘτ.”[Picture 4] “We can play music at the park,” said Big Brother. “I’m taking my η℘π,” Little Sister said, “I’m taking my γιμ.”[Picture 5] “What about the pets?” asked Little Sister. “We’ll take them with us” said Big Brother. “I’ll get φεIπ.” Little Sister said “I’ll get κοYφ.”[Picture 6] “Let’s go!” said Big Brother. “Yeah!” said Little Sister. They ran all the way to the park. What will they do at the park?

Episode 2

[Picture 1] Big Brother and Little Sister were swinging. Big Brother said “I can go higher than you!” Big Brother went very high. Little Sister said “I can go higher than that.” Big Brother pushed her very high. [Picture 2] “I can play music louder than you” said Little Sister. “No you can’t.” “Listen to me blow my η℘π,” said Big Brother. He blew his η℘π. “See how loud my η℘π is?” “Oh, yeah? Listen to me blow my γιμ” said Little Sister. She blew her γιμ. “See how loud my γιμ is?” [Picture 3] “I can eat more candy than you,” said Big Brother. Big Brother ran to the πιν. He got candy from the πιν. He stuffed all the candy from the πιν in his mouth. “Can you eat that much?” Little Sister ran to the μ□Iδ. She got candy from the μ□Iδ. She stuffed all the candy from the μ□Iδ in her mouth. Then, they got more candy for later. [Picture 4] “I can make our pets do more tricks than you,” said Little Sister. “Uh-uh,” said Big Brother. Big Brother made φεIπ do tricks. He made φεIπ roll-over. He made φεIπ jump up and down. Next, it was Little Sister’s turn. Little Sister made κοYφ do tricks. She made κoYϕ roll-over. She made κoYϕ jump up and down. [Picture 5] "I can hit more rocks with my toy than you," said Big Brother. Big Brother set up the rocks. Big Brother got out his ναYβ. He pointed the ναYβ at the rocks. He hit a rock with his ναYβ. Little Sister put the rock back. Little Sister got out her ωΘτ. She pointed the ωΘτ at the rocks. She hit a rock with her ωΘτ. [Picture 6] Big Brother looked at his watch. "It's time to go home." They walked home hand in hand. What will they play when they get home?

Episode 3

[Picture 1] Big Brother and Little Sister were playing hide n' seek in the back yard. Little Sister was hiding. Big Brother was trying to find her. "Where's Little Sister?" There she is, behind the tree! [Picture 2] "Let's hide our pets," said Big Brother. "I'll hide φεIπ. Don't make any noise φεIπ ." Little Sister looked and looked for φεIπ. "Here he is!" Little Sister said, "I'll hide κoYϕ. Don't make any noise κoYϕ." Big Brother looked and looked for κoYϕ. "I found him." [Picture 3] **"**Let's hide the horns," said Little Sister. Big Brother blew the η℘π. Then, he hid the η℘π behind a rock. Where's the η℘π? "I see it!" said Little Sister. Little Sister blew the γιμ. Then, she hid the γιμ behind a tree. Where's the γιμ? "I got it!" said Big Brother. [Picture 4] **"**Let's hide the toys," said Big Brother. Big Brother hid his ναYβ. Little Sister looked and looked for his ναYβ. She yelled "Here's your ναYβ." Little Sister hid her ωΘτ Big Brother looked and looked for her ωΘτ. He yelled "Here's your ωΘτ." [Picture 5] "Let's eat our leftover candy before mom and dad come home" said Little Sister. Big Brother got his candy from the πιν. He ate all his candy from the πιν. "MMM" he said, "the candy from the πιν is really good." Little Sister got her candy from the μ□Iδ. She ate all her candy from the μ□Iδ. "MMM" she said, the candy from the μ□Iδ is really good." [Picture 6] Just then mom and dad came home. "It's time to come inside now" said mom. "We need to make dinner." Little Sister cried again.

Footnotes

[1] Word frequency counts are available from a variety of sources including adult written (e.g., KuCera & Francis, 1967), adult spoken (e.g., Brown, 1984), child written (e.g., Rinsland, 1949), and child spoken (e.g., Kolson, 1960) databases.

[2] Note that the two-representation model we describe is a simplified and generic version of those described by Luce et al., 2000 and Gupta & MacWhinney, 1997. The interested reader is referred to the original manuscript for complete details of the full model. Also, we consider the ability of this model to account for both perception and production, although the original models focus primarily on one aspect of spoken word processing.

[3] In some cases, asymmetries have been noted in the effect of neighborhood density across perception and production. In fact some models, predict that dense neighborhoods should facilitate production (see MacKay, 1987; Vitevitch, 2001a).

[4] Note that computations of phonotactic probability are based on a 20,000 word dictionary generally consisting of uninflected word forms (see also see Jusczyk, Luce, & Charles-Luce, 1994; Luce, Goldinger, Auer, & Vitevitch, 2000; Storkel, in press; Storkel & Rogers, 2000; Vitevitch & Luce, 1998; 1999). Therefore, /z/ is considered to occur infrequently in uninflected word forms, although it may occur often as a plural morpheme. The status of lexical representations of inflected words is an open question.

Table 1

Experimental Results of Gierut et al. (1999) Study

Treatment Condition	Generalization Results
Frequent versus Infrequent	Frequent > Infrequent
Dense versus Sparse	Sparse > Dense
Frequent versus Dense	Frequent > Dense
Infrequent versus Dense	Infrequent > Dense
Infrequent versus Sparse	Infrequent ≥ Sparse
Frequent versus Sparse	Frequent = Sparse

Note. The symbol '>' indicates 'greater than' (e.g., treatment of sounds in frequent words resulted in significantly greater generalization learning than infrequent words). The symbol '≥' indicates 'greater than or equivalent' (e.g., treatment of sounds in infrequent words resulted in greater or equivalent generalization learning than sparse words). The symbol '=' indicates 'equivalent' (e.g., treatment of sounds in frequent words resulted in generalization learning that was equivalent to sparse words).

Table 2

Sample of Frequent Treatment Words

Word	Word Frequency	Neighborhood Density
fine	161	**28**
full	230	**15**
feed	123	**19**
far	427	**18**
family	331	0
field	274	9
final	156	6
forward	115	0

Note. Neighborhood density counts in bold indicate words from dense neighborhoods.

Table 3

<u>The phonetic transcription of the common and rare sound sequences and their corresponding referents as invented or adapted from published children's stories</u>.

Form Characteristics		**Referent Characteristics**		
Common	Rare	Category	Item 1	Item 2
ω Θ τ	ν αY β	Toys	punch toy (Geisel & Geisel, 1958; p. 53)	cork gun (Geisel & Geisel, 1958; p. 45)
η ℘ π	γ ι μ	Horns	orange trumpet downward orientation (Geisel & Geisel, 1954; p. 50)	yellow hand-held tuba (Geisel & Geisel, 1954; p. 50)
π ι ν	μ □I δ	Candy Machines	red candy + 1 shoot (invented)	blue candy + 2 shoots (invented)
κ οY φ	φ εI π	Pets	green gerbil with antenna (DeBrunhoff, 1981; p. 132)	purple mouse-bat (Mayer, 1992, p. 43)

Figure Captions

Figure 1. Illustration of a two-representation connectionist model of word processing for the word “sit.” Lexical representations are illustrated with rectangles. The thickness of the rectangle indicates the resting threshold as determined by word frequency (e.g., “sit” infrequent). Inhibitory connections between words are indicated by lines terminating in circles. The number of connections between words illustrates neighborhood density (e.g., neighborhood of “sit” is dense). Phonological representations are illustrated with circles. The thickness of the circle indicates the resting threshold based on phonotactic probability (e.g., /σ/, /I/, and /τ/ common). Facilitory connections between sounds are indicated by lines terminating in arrows. The thickness of the connecting line indicates the strength of the relationship based on phonotactic probability (e.g., /σI/ and /Iτ/ common).

Figure 2. Illustration of a two-representation connectionist model of word processing for the word “these.” Lexical representations are illustrated with rectangles. The thickness of the rectangle indicates the resting threshold as determined by word frequency (e.g.,“these” frequent). Inhibitory connections between words are indicated by lines terminating in circles. The number of connections between words illustrates neighborhood density (e.g., neighborhood of “these” is sparse). Phonological representations are illustrated with circles. The thickness of the circle indicates the resting threshold based on phonotactic probability (e.g., /Δ/, /ι/, and /ζ/ rare). Facilitory connections between sounds are indicated by lines terminating in arrows. The thickness of the connecting line indicates the strength of the relationship based on phonotactic probability (e.g., /Δι/ and /ιζ/ rare).