Tutorial

Implementing Evidence-Based Practice: Selecting Treatment Words to Boost Phonological Learning

Holly L. Storkel[a]

Purpose: Word selection has typically been thought of as an inactive ingredient in phonological treatment, but emerging evidence suggests that word selection is an active ingredient that can impact phonological learning. The goals of this tutorial are to (a) review the emerging single-subject evidence on the influence of word characteristics on phonological learning in clinical treatment, (b) outline hypotheses regarding the mechanism of action of word characteristics, and (c) provide resources to support clinicians incorporating word selection as an active ingredient in their approach to phonological treatment.
Method: Research demonstrating the influence of the word frequency, neighborhood density, age of acquisition, and lexicality of treatment stimuli on phonological learning is summarized. The mechanism of action for each characteristic is hypothesized. Methods from the research studies are used to create a free set of evidence-based treatment materials targeting most of the mid-8 and late-8 consonants.
Results: Clinicians have numerous evidence-based options to consider when selecting stimuli for phonological treatment including (a) high-frequency and high-density words, (b) low-frequency and high-density words, (c) high-frequency and mixed-density words, (d) low-frequency and late-acquired words, and (e) nonwords.
Conclusion: Incorporating word characteristics into phonological treatment may boost phonological learning.
KU ScholarWorks Supplemental Material: http://hdl.handle.net/1808/24768

Turkstra, Norman, Whyte, Dijkers, and Hart (2016) recently outlined the importance of specifying treatment methods in terms of the targets (i.e., "specific aspects of functioning intended to change as a result of treatment," p. 165), ingredients (i.e., "specific actions taken by the clinician to effect changes in the target," p. 165), and mechanism of action (i.e., "known or hypothesized means by which ingredients exert their effects," p. 165). For phonological treatment, the target is typically broad, systemwide change in phonology. In addition, many of the active ingredients are well researched, such as how to select sounds for treatment (Baker & McLeod, 2011b; Gierut, 2001, 2006; Powell, 1991) and what activities to do during treatment (Baker & McLeod, 2011a). Interestingly, word selection has typically been thought of as an inactive ingredient, namely an action that is "not expected to change the target" (Turkstra et al., 2016, p. 168). However, emerging evidence suggests that word selection is an active ingredient in phonological treatment that can influence phonological learning. This idea is well aligned with current theories, which suggest that growth of the lexicon (the mental store of word forms and their meanings) and phonology are related (Beckman & Pierrehumbert, 2004; Edwards, Munson, & Beckman, 2011; Stoel-Gammon, 2011; Vihman, 2017). This alignment with theory allows consideration of the mechanism of action to understand how word characteristics can influence phonological learning during treatment. The goals of this tutorial are to (a) review the emerging evidence on the influence of word characteristics on phonological learning, (b) outline hypotheses regarding the mechanism of action, and (c) provide resources so that clinicians can incorporate word selection as an active ingredient in their clinical practice.

Theoretical Foundation

How do phonology and the lexicon relate to one another, especially when sounds are produced inaccurately? There is controversy about the underlying lexical representation of misarticulated words (e.g., [wod] for target /rod/ "road"), where "lexical representation" refers to the

[a]Speech-Language-Hearing: Sciences & Disorders, University of Kansas, Lawrence

Correspondence to Holly L. Storkel: hstorkel@ku.edu

Editor-in-Chief: Shelley Gray
Editor: Kerry Ebert

Received August 7, 2017
Revision received September 14, 2017
Accepted October 12, 2017
https://doi.org/10.1044/2017_LSHSS-17-0080

Disclosure: The author has declared that no competing interests existed at the time of publication.

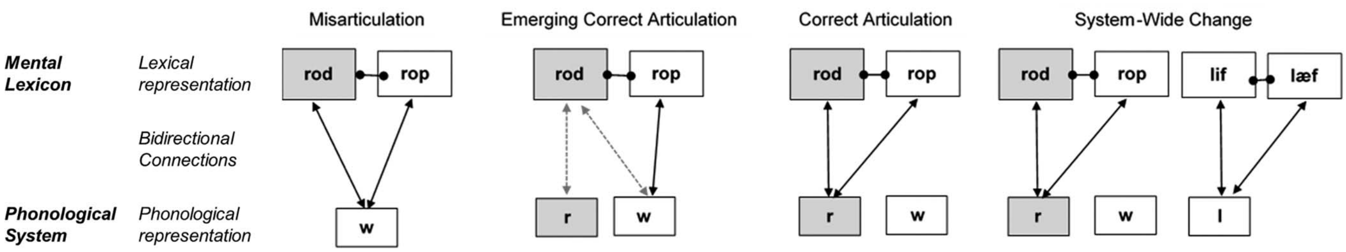
mental representation of the word form, as a whole unit, in the mental lexicon. Some argue that the child's underlying lexical representation approximates the target (Dinnsen, 2002; Dinnsen, O'Connor, & Gierut, 2001; Storkel, 2004; Storkel, Maekawa, & Aschenbrenner, 2013). Thus, a child who produces [wod] for target /rod/ (i.e., "road") is assumed to store some version of the target word form /rod/ in the mental lexicon, and the misarticulation arises in the connection between the lexical representation in the mental lexicon and the representation of the target sound in the phonological system. This perspective has been supported by speech perception evidence: specifically, the ability of the child to correctly perceive the difference between the target and the substitute (Locke, 1980; McGregor & Schwartz, 1992; Tyler, Edwards, & Saxman, 1990). In addition, evidence of covert contrasts, namely fine-grained acoustic or transcription differences between the production of a sound (e.g., [w]) as a substitute for another target sound (e.g., /r/) versus the production of the same sound (e.g., [w]) as an accurate target (e.g., /w/), supports the hypothesis that children potentially maintain a difference between the target and the substitute at some level of the linguistic system (Gierut & Dinnsen, 1986; Locke, 1979; Maxwell & Weismer, 1982; Munson, Edwards, Schellinger, Beckman, & Meyer, 2010; Munson, Johnson, & Edwards, 2012; Munson, Schellinger, & Urberg, 2012; Tyler et al., 1990; Weismer, Dinnsen, & Elbert, 1981). Others argue that the child's underlying lexical representation of misarticulated words approximates the child's pronunciation, in many cases citing evidence related to difficulty with speech perception or a lack of covert contrast or other factors (Macken, 1980; Maxwell, 1984; Vihman, 1982). In this scenario, a child who produces [wod] for target /rod/ is assumed to store a version of the incorrect misarticulated word form /wod/ in the mental lexicon, and the misarticulation may be further reinforced elsewhere in the speech-language system.

Clinically, it is difficult to assess children's underlying lexical representations so it may not be possible to know with certainty whether children's lexical representation of a misarticulated word approximates the target or the misarticulated production. For this tutorial, I will assume that the first hypothesis is correct and that the child's underlying lexical representation of misarticulated words approximates the target (e.g., /rod/). Note further that the underlying lexical representation is characterized as approximating the target. This terminology is used purposely to capture the idea that underlying lexical representations in any young child may not be adultlike. Specifically, the lexical representation may be underspecified, lacking detail (Metsala & Walley, 1998; Storkel, 2002; Vihman, 2017), or other alternative options that will be described when relevant. As an example of a lack of detail, the lexical representation of target /rod/ ("road"), which the child produces as [wod], could be /*sonorant* od/ or /ro *stop*/. As this example shows, the lack of detail may relate to the erred production (e.g., /*sonorant* od/) or may be unrelated (e.g., /ro *stop*/). Note that when the underspecification relates to the misarticulation (e.g., /*sonorant* od/), the lexical representation may be consistent with both the target and the substitute, creating a compromise between the two previously described dichotomous positions on the nature of the lexical representation. This tutorial will illustrate the mechanism of action during phonological treatment based on a lexical representation that closely approximates the adult target to place greater emphasis on how the lexicon influences phonological learning during treatment, but it is important to recognize that the relationship is likely bidirectional (Vihman, 2017), such that lexical representations may also be changing in ways that have not previously been systematically tracked in phonological treatment.

Although there is controversy surrounding the exact nature of the lexical representation of misarticulated words in the lexicon, the lexicon and the phonological system potentially interact during phonological treatment. The first panel of Figure 1 shows the lexical representation for the misarticulated words /rod/ ("road") and /rop/ ("rope") under the previously discussed assumption that the representations approximate the adult target. These two lexical representations are connected to one another because they are lexical neighbors due to their phonological similarity. The lexical representations in the mental lexicon are connected to representations of phonemes, termed the phonological representation, in the phonological system (Werker & Curtin, 2005). Note that only the phonological representation for the first sounds in the words is shown in Figure 1. Also, note that the connection between the lexical representations in the mental lexicon and the phonological representations in the phonological system is bidirectional to indicate the potential interaction between the two systems (Vihman, 2017). That is, thinking, hearing, or saying the word "road" could activate or bring to mind a sound, potentially /w/ in this case, and vice versa. Finally, notice that no representation for /r/ exists in the phonological system because the child has not yet learned this sound. Instead, the lexical representations for "road" and "rope are connected to the phonological representation for /w/, leading to the misarticulation of "road" and "rope" as [wod] and [wop], respectively.

The remaining panels of Figure 1 illustrate the mechanism of action during phonological treatment. During phonological treatment, the child repeatedly practices a subset of words containing the target /r/. For example, "road" is selected for practice in treatment, and this is noted in Figure 1 by shading. Through practice and feedback, the child creates a new mental representation of /r/ in the phonological system, as shown in the second panel of Figure 1, and connects this to the treated words in the mental lexicon (e.g., "road"). That is, the word form /rod/ in the mental lexicon weakens its connection to [w], as indicated by a dashed gray connection between the lexical and phonological representations, and creates a connection to [r] in the phonological system, supporting correct production of the target "road." The third panel of Figure 1 illustrates the strengthening of this new connection between the treated word ("road") and the newly learned sound (/r/) as well as the loss of a connection between the treated word ("road")

Figure 1. Sequence of hypothesized changes that may occur during phonological treatment. The treated sounds and words are shaded. Untreated sounds and words are not shaded. Note that changes may not occur in the stepwise manner shown. The depicted changes could overlap one another.



and the substitute sound ([w]). These underlying changes in the lexicon, phonological system, and the connection between the two support correct production of the treated sound in the treated words.

At the same time, as shown in the third panel of Figure 1, untreated words containing the target sound (e.g., “rope”) must also undergo this same change of deleting a connection to the incorrect substitute [w] and creating a new connection to the new sound [r] in the phonological system. This process is referred to as “lexical diffusion,” the process whereby change in the phonological system permeates word forms. This third panel of Figure 1 illustrates the emergence of correct production of the treated sound (e.g., /r/) in untreated words.

Also of note and shown in the last panel of Figure 1, adding /r/ to the phonological system could trigger additional changes in the phonological system, yielding new phonological representations of additional sounds. For example, the last panel in Figure 1 shows the addition of /l/ to the phonological system. The addition of /l/ to the phonological system also requires changes in the connections between the mental lexicon and the phonological system. As shown in the last panel of Figure 1, the new phonological representation for /l/ undergoes lexical diffusion, forming connections with lexical representations of words containing /l/, such as “leaf” and “laugh.” Thus, this last panel of Figure 1 illustrates systemwide change in phonology.

Taken together, the panels of Figure 1 illustrate the bidirectional relationship between lexical and phonological representations during phonological treatment. Sounds are practiced in words to facilitate creation of a new phonological representation (second panel). This new phonological representation must now connect with existing lexical representations (third panel). These two components index learning of the treated sound, but the addition of a new sound to the phonological system may facilitate further change in the phonological system, resulting in learning beyond what was explicitly taught in treatment (last panel). See Vihman (2017) and Curtin and Zamuner (2014) for a similar description applied to typically developing younger children. Because of this interaction between lexical and phonological representations during treatment, characteristics of words may influence success. Characteristics that have been investigated are (a) word frequency, (b) neighborhood density, (c) age of acquisition (AoA), and (d) lexicality. Each of these variables will be reviewed, in turn.

Word Frequency and Neighborhood Density

“Word frequency” is the number of times a word occurs in a language. In practice, word frequency is typically computed by finding a representative sample of the language and counting the number of times a word occurs within that sample. Samples typically vary in the dialect of English (e.g., American vs. British English), the age of the individuals contributing to the sample (e.g., child vs. adult), and the modality of the sample (e.g., spoken vs. written). Gierut and Dale (2007) compared word frequency across four samples of American English: adult written (Kucera & Francis, 1967), child written (Rinsland, 1949), adult spoken (Brown, 1984), and child spoken (Kolson, 1960). Generally, word frequency was correlated across corpora. There is no universally agreed upon cutoff for determining whether a word is low or high frequency. In many cases, low versus high frequency may be determined using a relative definition. For example, Gierut and Dale used the mean for their words of interest in the Kucera and Francis written adult database to further code those words as being low or high frequency. An example of a low-frequency word is “raccoon,” which did not occur in the Kucera and Francis corpus (i.e., frequency = 0), which is below the mean of the words of interest (i.e., 118). In contrast, an example of a high-frequency word is “road,” which occurred 197 times in the Kucera and Francis corpus, which is above the mean of 118. Notably, Gierut and Dale showed that coding of words into low- and high-frequency categories in this manner across different corpora leads to similar conclusions about the influence of word frequency on phonological learning. Thus, it may not be critical to match the word frequency corpus exactly to the client. Word frequency is correlated with neighborhood density (Landauer & Streeter, 1973). Therefore, the influence of frequency on treatment has tended to be studied in tandem with density.

"Neighborhood density" refers to the number of words that are phonologically similar to a given word. "Phonologically similar" is typically defined as words that differ from a given word by one sound. For example, neighbors of "road" (/rod/) include "node" (/nod/), "rid" (/rɪd/), "roam" (/rom/), "row" (/ro/), and "ode" (/od/). Note that the first three examples involve a single sound substitution in each word position, whereas the last two examples illustrate a single sound deletion in different word positions. A single sound addition also would be counted as a neighbor, but there are no examples of this type of neighbor for "road." Like word frequency, neighborhood density is determined by searching a corpus for words that are phonologically similar to each target word. Although the exact neighborhood density does tend to differ across corpora (Storkel, 2013; Storkel & Hoover, 2010), measures across corpora tend to be correlated (Storkel, 2013; Storkel & Hoover, 2010). Although there are differing definitions of high and low density, in the phonological treatment literature, a density of 10 neighbors is a common cut-point for high versus low density (Gierut & Morrisette, 2012b; Gierut, Morrisette, & Champion, 1999; Morrisette & Gierut, 2002). Using an adult-written corpus (the Hoosier Mental Lexicon), road has 29 neighbors and would be considered high density. In contrast, raccoon has 0 neighbors and would be coded as low density. These two examples illustrate the relationship between frequency and density: "road" is high density and high frequency, whereas "raccoon" is low density and low frequency.

Treatment Word Selection: Frequency × Density

A series of three single-subject studies by Gierut and colleagues (Gierut & Morrisette, 2012b; Gierut et al., 1999; Morrisette & Gierut, 2002) has examined the combined influence of word frequency and neighborhood density on phonological treatment outcomes. In the first study (Gierut et al., 1999), children were taught two sounds in an alternating treatment single-subject design. Each sound was taught in a different type of word so that low versus high frequency and low versus high density could be pitted against each other. Children were taught their target sound in eight words that shared the word characteristic of interest (e.g., high frequency) and then the characteristic that was not of interest was balanced. For example, in the high-frequency condition, four of the high-frequency words were low density, and four of the high-frequency words were high density. In general, children taught sounds in high-frequency words tended to improve accuracy of the treated sound and untreated sounds that shared manner with the treated sound. Likewise, low-density words were also effective in promoting improved production of the treated sound and untreated sounds from the same manner class as the treated sound. Morrisette and Gierut (2002) essentially replicated and expanded this finding with a multiple-baseline single-subject design. In this study, it was once again shown that treatment of a sound in high-frequency words led to appreciable change in the accuracy of the treated sound, untreated sounds within the same manner class, and untreated sounds from other manner classes. Thus, the greatest systemwide change was observed for treatment of sounds in high-frequency words. Treatment of sounds in low-density or low-frequency words resulted in sound change, but the learning was narrow (i.e., change in the treated sound only for low density, change in unrelated sounds only for low-frequency words). Minimal sound change occurred when a sound was treated in high-density words. Thus, across these two studies, high frequency emerged as the primary factor facilitating phonological learning.

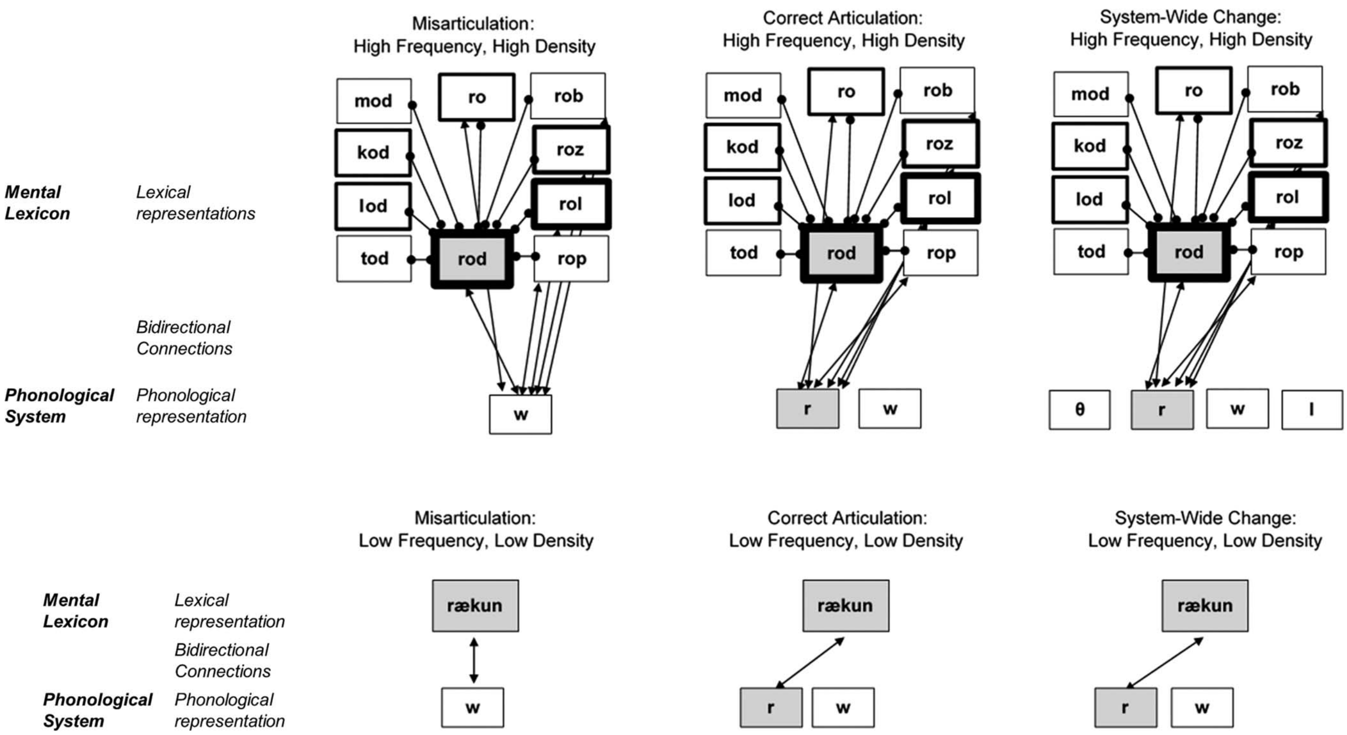
In the most recent single-subject multiple-baseline study in the series (Gierut & Morrisette, 2012b), a different tactic was used. Here, frequency and density were fully crossed, yielding four conditions: (a) high frequency, high density; (b) high frequency, low density; (c) low frequency, high density; and (d) low frequency, low density. In terms of the outcome, treatment of sounds in high-frequency and high-density words resulted in the largest effect size (d = 14.83) of the four combinations tested, with significant improvements in accuracy noted for sounds that were produced incorrectly at pretreatment. Thus, broad systemwide change was observed with treatment of high-frequency and high-density words in combination. It also is notable that treatment of sounds in low-frequency and high-density words resulted in strong learning with a large effect size (d = 11.39). Thus, in this study, dense neighborhoods seemed to emerge as the primary factor driving phonological learning. Note that in Bellon-Harn, Credeur-Pampolina, and LeBoeuf's (2013) single-subject multiple-baseline study, dense neighborhoods also emerged as the primary word characteristic driving phonological learning in a more naturalistic treatment approach.

Taken together, these four single-subject studies show that when only frequency or density is manipulated in isolation and the other characteristic is balanced (i.e., equal mix of high and low), high-frequency words promote broad systemwide change. In contrast, when frequency and density are manipulated in tandem, high density promotes broad systemwide change. The difference in findings across word selection methods likely has to do with the coupling and consistency of the characteristics during treatment (Gierut, 2016). In the first scenario, frequency and density are uncoupled, with one characteristic being consistent and the other being inconsistent. In the second scenario, frequency and density are coupled, with each characteristic being consistently high or low. This uncoupling or coupling appears to influence which characteristic is the primary driver of phonological learning (Gierut, 2016). Thus, there are several effective options for using frequency and density to guide selection of words for treatment.

Mechanism of Action: Frequency × Density

Figure 2 illustrates sound change when frequency and density are coupled during treatment by comparing

Figure 2. Sequence of hypothesized changes that may occur during phonological treatment for the high-frequency and high-density treated word "road" (/rod/) and the low-frequency and low-density treated word "raccoon" (/rækun/). Treated sounds and words are shaded. Density is illustrated by the number of connections to other similar-sounding words. Frequency is illustrated by the weight of the line around the word (i.e., heavier lines indicate higher frequency). The final panel illustrates the difference between high-frequency/high-density and low-frequency/low-density treated words in promoting broader phonological learning, consistent with the findings of Gierut and Morrisette (2012b).



high-frequency and high-density words (top panel) versus low-frequency and low-density words (bottom panel). Word frequency is depicted in Figure 2 by the thickness of the box with higher-frequency words (e.g., /rod/ "road") having thicker boxes than lower-frequency words (e.g., /rækun/ "racoon"). Density is depicted by the number of lexical representations connected to the lexical representation of the target word. Thus, higher-density words (e.g., /rod/ "road") have more connected lexical representations than lower-density words (e.g., /rækun/ "racoon"). Note that only a subset of neighbors is illustrated for the dense word "road" due to space limitations. The first panel of Figure 2 illustrates the lexical and phonological representations and their connections at the start of treatment. The second panel illustrates learning of the treated sound in both treated and untreated words. The final panel illustrates additional change in the phonological system because of learning the treated sound. Note that this final panel depicts the broader phonological learning that occurred with treatment of high-frequency and high-density words compared to treatment of low-frequency and low-density words, consistent with the findings of Gierut and Morrisette (2012b).

There are several possible reasons why high-frequency words may be particularly well suited for triggering sound change. One argument (Gierut et al., 1999; Morrisette & Gierut, 2002) is that high-frequency words ease language processing demands. Specifically, high-frequency words are retrieved from the lexicon more rapidly than low-frequency words (see Ambridge, Kidd, Rowland, & Theakston, 2015, for review). Likewise, they are easier to hold in working memory (see Ambridge et al., 2015, for review). Thus, high-frequency words may reduce language processing demands so that children have more language processing capacity available to focus on the production training that is being provided, supporting successful learning of the treated sound (Gierut, 2016). Likewise, reduced language processing demands may allow more language processing capacity to be devoted to learning beyond the treated sound in the treated words, supporting greater generalization of the treated sound to untreated words and/or learning of untreated sounds (Gierut, 2016). These same advantages would not occur for low-frequency words. That is, low-frequency words would be more difficult to retrieve and hold in working memory, potentially leaving little language processing capacity for learning during production training.

In terms of density, it is possible that elements of the frequency explanation apply. That is, high-density words are easier to hold in working memory (Roodenrys & Hinton, 2002; Thomson, Richardson, & Goswami, 2005; Thorn & Frankish, 2005), potentially allowing more language processing capacity to be devoted to production training, facilitating learning of the treated sound in the treated words as well as broader generalization (Gierut, 2016). In contrast, low-density words would be more difficult to hold in working memory, potentially leaving little language processing capacity to devote to production training.

Figure 2 illustrates several additional potential benefits of high density. On the one hand, rhyme neighbors form minimal pairs with the treatment target, contrasting the treated sound with other known and unknown sounds in the language (e.g., /rod/ vs. /tod/, /lod/, /kod/, /mod/). This potential for internal comparison between sounds may facilitate phonological learning (Gierut, 2016; Gierut & Morrisette, 2012b) in a manner similar to the explicit comparison between sounds that occurs during minimal pair treatment, which has a strong evidence base (Barlow & Gierut, 2002; Gierut, 1989, 1990, 1991). This type of contrast may facilitate systemwide sound change because the internal comparison between sounds may spark learning of untreated sounds.

On the other hand, body neighbors highlight other words in the language that contain the treated sound and following vowel (e.g., /rod/ vs. /rop/, /rol/, /roz/, /rob/, /ro/). These neighbors present instances of the same sound produced in slightly different ways due to the lack of invariance across words (Gierut, 2016). This may further help to define the boundaries for production of the target sound, specifically facilitating learning of contextual variation in production of the target sound. This could enhance learning of the treated sound. In addition, this could also facilitate lexical diffusion of the treated sound to untreated words because the dense neighborhood offers a direct link to untreated words containing the treated sound. This is shown in the second upper panel of Figure 2, where many neighbors of /rod/ form connections with the newly learned treated sound /r/. It should be noted, however, that lexical diffusion does occur across neighborhoods (Gierut & Morrisette, 2012b). Gierut and Morrisette examined the characteristics of the words that changed from incorrect to correct productions and showed that lexical diffusion was widespread and not narrowly confined to specific lexical neighborhoods. In other words, dense neighborhoods may trigger diffusion within the neighborhood that then extends beyond the neighborhood to the broader lexicon.

These same benefits would not accrue for low-density neighborhoods, as illustrated in the bottom panels of Figure 2, especially the second panel. Words in low-density neighborhoods would be more difficult to hold in working memory, leaving less language processing capacity available to focus on production training. In addition, the low-density neighborhood offers few opportunities for contrasting the target word with other sounds in the language (i.e., few rhyme neighbors) or for identifying other words of the language that contain the target (i.e., few body neighbors). To summarize, the mechanism of action for both frequency and density relates to the ease or difficulty in retrieving words from the lexicon and the ease or difficulty of holding words in working memory during therapy activities. In addition, density also relates to the number of opportunities to highlight how the sound is used in the words of the language.

Implementation Resource: Frequency × Density

I sought to identify high-frequency and high-density words using the same corpus and operational definitions as the prior studies by Gierut and colleagues (Gierut & Morrisette, 2012b; Gierut et al., 1999; Morrisette & Gierut, 2002) so that clinical implementation will closely follow the methods used to establish treatment efficacy. Of course, clinicians can depart from those methods to better meet the needs of a specific child, but it would be important to think carefully about whether methodological departures could potentially lead to different results and to regularly collect data to monitor progress to ensure that modified methods are effective for the target child. Note that Bellon-Harn et al. (2013) did not use preselected words in their naturalistic treatment approach. Clinicians who prefer a naturalistic approach are directed to that article to determine how to implement word characteristics in a naturalistic approach. In terms of procedures for preselecting words, word frequency was taken from Kucera and Francis (1967), and neighborhood density was computed by searching the Hoosier Mental Lexicon to find neighbors of each word. The Hoosier Mental Lexicon (Nusbaum, Pisoni, & Davis, 1984) is a resource of approximately 20,000 words taken from an abridged dictionary (Webster's Seventh Collegiate Dictionary, 1967). I also followed Gierut and Morrisette's (2012b) definition of high versus low frequency (i.e., high frequency = 100 or more occurrences in Kucera and Francis's sample of 1 million words; low frequency = 99 or fewer occurrences) and high versus low density (i.e., high density = 10 or more neighbors; low density = 9 or fewer neighbors). Gierut and Morrisette selected words to target /f s l r/ in initial position. I attempted to select words to target six of the mid-8 /k g f v ʧ ʤ/ and seven of the late-8 sounds / θ ð s z ʃ l r / in initial position. From the mid-8, / ŋ / was excluded because it does not occur in initial position and / t / was excluded because I felt that it was less likely to be a treatment target. From the late-8, / ʒ / was excluded due to low occurrence in English. Gierut and Morrisette selected eight words for each target sound. I selected six words because of the difficulty in identifying eight words for certain sounds and because six words have been used in other treatment studies (e.g., Gierut & Morrisette, 2012a).

Supplemental materials are located at KU ScholarWorks, a digital repository of the University of Kansas. All materials relevant to this article are located at http://hdl.handle.net/1808/24768 and are licensed under a Creative Common Attribution-NonCommercial 4.0 International License. This license allows users to share and adapt the materials, on the condition that appropriate credit is given and that the use of the materials is not for commercial purposes. More information about the license is available at https://creativecommons.org/licenses/by-nc/4.0/. Relevant to the current discussion, the ScholarWorks supplement includes an Excel workbook entitled *1. FreqDensList* consisting of several worksheets: *ReadMe* (provides a summary of how the words were selected), *Klatt* (introduces the computer readable and searchable transcription system used), *RealWords* (contains the list of words for each target sound, including frequency and density values), and *DataSheet* (provides grids for tracking number of production trials and production accuracy for 21 sessions). Also available in the ScholarWorks supplement is a PowerPoint file (*1. FreqDensPic*) containing a corresponding picture for each target word. Pictures were taken from https://pixabay.com/. Only pictures released under Creative Commons CCO, which is a public domain license, were used. Six high-frequency and high-density words were found for targets / k g f s l r /. Unfortunately, six high-frequency and high-density words meeting Gierut and Morrisette's (2012b) definitions did not exist for the remaining targets. Therefore, a different evidence-based approach was used for these sounds based on the types of words available.

For targets / v θ z ʃ ʧ ʤ /, there were very few high-frequency words containing these targets in word-initial position, but there were many low-frequency words and a good mix of low- and high-density words. Thus, six low-frequency and high-density words were selected based on the findings of Gierut and Morrisette (2012b). Specifically, although high-frequency and high-density words lead to the largest effect size (d = 14.83), the next best condition was low-frequency and high-density words, which still had a large effect (d = 11.39, where a d of 10.1 or greater is considered a large effect for phonological treatment; Gierut, Morrisette, & Dickinson, 2015). Given the lack of high-frequency words, low-frequency and high-density words appeared to be the best word selection strategy for these sounds based on the available words and the available research evidence.

For target / ð /, there were only a small number of words containing this sound in word-initial position. All of the words were high frequency, but there were not enough to select only high density. Thus, high-frequency words varying in density were selected, such that three words were low density and three words were high density. This matches Morrisette and Gierut's (2002) high-frequency, mixed-density condition.

Turning to other issues of implementation, Gierut and Morrisette (2012b) and Morrisette and Gierut (2002) saw children three times weekly in 1-hr sessions. This treatment schedule is on the higher end of the typical treatment intensity observed in research studies (i.e., two to three 30- to 60-min one-on-one sessions per week; Baker & McLeod, 2011a) and in clinical practice (i.e., one to three 20- to 30-min group sessions per week; Brandel & Loeb, 2011). A lower-intensity treatment schedule may still be effective, but clinicians are cautioned that treatment intensity is an important component of effective phonological treatment (see Allen, 2013, who demonstrated that three 30-min sessions per week was more effective than one 30-min session). Consequently, monitoring child progress would be important if a lower-intensity treatment schedule is used. An additional component of treatment intensity is the number of production attempts or trials per session. Unfortunately, number of trials achieved or targeted in a treatment session was not reported for either study. In terms of general guidance, Williams (2012) recommended a minimum dose of 50 trials per session and further suggested that the minimum dose be increased to 70 trials per session for children with more severe phonological disorders. The data sheet notes the number of production attempts achieved at different stopping points during a session and highlights the points when 54 or 72 trials have been achieved as a reminder of Williams's recommended targets. Note that Williams's guidelines were generated from a post hoc analysis of treatment data rather than being experimentally established through systematic testing of different intensities.

In the research studies (Gierut & Morrisette, 2012b; Morrisette & Gierut, 2002), drill-play production practice occurred in imitation until the child achieved 75% accuracy producing the treated sound in the treated words across two consecutive sessions or until a maximum of seven sessions had been completed. Spontaneous production then occurred until the child produced the treated sound in the treated words with 90% accuracy across three consecutive sessions or until a maximum of 12 sessions had been completed. Thus, the maximum number of sessions was 19. If the intensity in the clinical setting is like the intensity in the research study, then these maximum session criteria are useful in comparing a child's progress to progress in the research study. That is, a child who is making good progress should achieve the accuracy criteria or be close to achieving the accuracy criteria in the stated maximum number of sessions. However, if the intensity in the clinical setting is lower, then the child may need more sessions to achieve the accuracy criteria, and thus, progress may be slower. Williams (2012) suggested that approximately 30 sessions was a typical treatment duration for children with phonological disorders but that approximately 40 sessions might be needed for children with more severe phonological disorders. In the supplemental Excel file, a grid is provided to tally correct and incorrect productions for each practice session to aid clinicians in monitoring treatment progress. If used electronically, the worksheet automatically calculates accuracy. Data sheets are provided for 21 sessions, but a new Excel file can be started if more sessions are needed. Of course, additional measures beyond treatment progress (e.g., generalization) would also be important in ensuring that appropriate gains are being made by an individual child.

AoA

"Age of acquisition" (AoA) is the estimated age when a word was learned. Typically, AoA is generated by asking adults to rate on a 5- or 7-point scale the approximate age when they think they learned a word (Bird, Franklin, & Howard, 2001; Carroll & White, 1973; Gilhooly & Logie, 1980; Snodgrass & Yuditsky, 1996). Thus, AoA databases may not reflect the actual average age when children typically acquire a word but do tend to correlate with the actual average age when children acquire a word (e.g., Baumeister, 1985; Gilhooly & Gilhooly, 1980). In other words, AoA ratings do tend to accurately divide words into those that were earlier or later acquired. AoA tends to correlate with word frequency, such that late AoA words tend to be low frequency and early AoA words tend to be high frequency (e.g., Carroll & White, 1973). Psychololinguistic studies have attempted to differentiate AoA from frequency effects and generally suggest that each has an independent and unique influence on language processing (e.g., Barry, Morrison, & Ellis, 1997; Carroll & White, 1973; Cirrin, 1984; Gerhand & Barry, 1998; Snodgrass & Yuditsky, 1996; Turner, Valentine, & Ellis, 1998). Given this correlation, it is important to differentiate the impact of AoA and word frequency on clinical treatment.

Treatment Word Selection: AoA × Frequency

To our knowledge, only a single study has examined AoA in phonological treatment (Gierut & Morrisette, 2012a). Gierut and Morrisette sought to differentiate the effects of AoA and word frequency in phonological treatment using a single-subject research design. Children were taught a target sound in one of four possible types of words: (a) early acquired, high frequency; (b) early acquired, low frequency; (c) late acquired, high frequency; and (d) late acquired, low frequency. Results showed that children made greater change in accuracy of treated and untreated errored sounds when treatment incorporated late-acquired words than when treatment incorporated early-acquired words, regardless of word frequency. That is, AoA seemed to have a greater influence on phonological learning than word frequency.

Mechanism of Action: AoA

Turning to the potential mechanism of action for AoA, late-acquired words are thought to have more vulnerable, more fragile, or less elaborate representations (e.g., Baumeister, 1985; Hirsh & Ellis, 1994; Walley, Metsala, & Garlock, 2003), which may mean that the representations of these words are easier to change. In contrast, the representations of early-acquired words may be more robust, more entrenched, and more elaborate (e.g., Baumeister, 1985; Hirsh & Ellis, 1994; Walley et al., 2003), which may mean that it is more difficult to change the representation of these words. As shown in the top panel of Figure 3, a late-acquired word (e.g., “roof”) may have a weaker connection between the mental representation in the lexicon and the representation of sounds in the phonological system, as indicated by the thickness of the connecting line in Figure 3. The connection may be weaker (top first panel of Figure 3) because the word has been recently learned so the connection across representations is still being established. Thus, it may be easier to disconnect the representation of the word from the errored sound, as shown in the top second and third panels of Figure 3, and establish a connection with the correct target sound, as shown in the top second and third panels of Figure 3. This ease of changing the connection between representations in the lexicon and the phonological system then may allow greater language processing capacity to be devoted to phonological change, facilitating learning of the treated sound as well as broader learning (i.e., systemwide change), which is shown in the top final panel of Figure 3, where new untreated sounds (/θ l/) have been added to the phonological system.

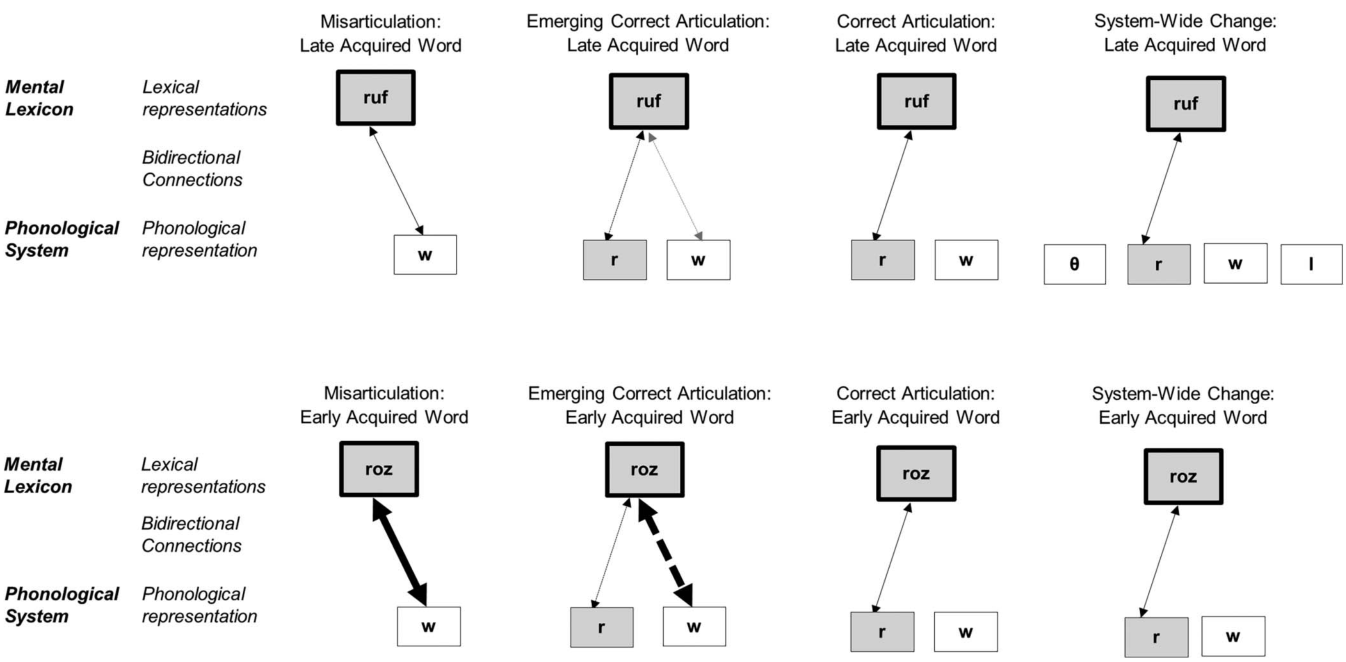
In contrast, as shown in the bottom panel of Figure 3, an early-acquired word (e.g., “rose”) may have stronger connections between the representation of the word form in the lexicon and the substituted sound in the phonological system because the word was learned earlier in development, allowing the connection between the representations in the lexicon and the phonological system to be strengthened. Thus, as shown in the bottom second and third panels of Figure 3, more effort may be needed to sever this strong lexical–phonological connection and establish a new connection with the correct target sound. This more effortful disconnecting of the lexical and phonological representations may leave little language processing capacity for phonological change. Thus, phonological change is narrow with minimal learning beyond the treated sound, as shown in the bottom final panel of Figure 3. Taken together, the mechanism of action for AoA is hypothesized to relate to the ease or difficulty of breaking the existing connection between the word and the substituted sound.

Implementation Resource: AoA

To facilitate implementation of late-acquired words in clinical treatment of phonological disorders, I attempted to follow the procedures of Gierut and Morrisette (2012a) to create a set of treatment words for six of the mid-8 singletons /k g f v ʧ ʤ/ (excluding / ŋ t /) and seven of the late-8 singletons / θ ð s z ʃ l r / (excluding / ʒ /). Per the procedures of Gierut and Morrisette, six words were selected for each target sound. AoA and word frequency values were taken from the same sources used by Gierut and Morrisette (Bird et al., 2001; Gilhooly & Logie, 1980; Kucera & Francis, 1967). Specific cutoffs were not identified by Gierut and Morrisette. They note that the mean AoA rating for their late-acquired words was four, so I eliminated all words with an AoA rating of three and lower and then attempted to select words for each target sound so that the mean of the treated words for each sound was an AoA rating of four or greater. I selected low-frequency words using the previously reported cutoffs of Gierut and Morrisette (2012b, i.e., less than 100) because the low-frequency and late AoA condition produced the strongest phonological learning. Finally, as reported by Gierut and Morrisette (2012a), I attempted to select more high-density than low-density words based on the cutoffs of Gierut and Morrisette (2012b, i.e., 10 or higher defines high density).

Relevant materials in the ScholarWorks supplement include an Excel workbook entitled *2. AoAList* consisting of several worksheets: *ReadMe* (provides a summary

Figure 3. Sequence of hypothesized changes that may occur during phonological treatment for the late-acquired word "roof" (/ruf/) and the early-acquired word "rose" (/roz/). Treated sounds and words are shaded. Age of acquisition is depicted by the thickness of the connection between the word and its initial sound (i.e., thicker lines indicate stronger connections due to earlier acquisition). The final panel illustrates the difference between late-acquired and early-acquired treated words in promoting broader phonological learning, consistent with the findings of Gierut and Morrisette (2012a).



of how the words were selected), *LateAoATxWords* (contains the list of words for each target sound, including AoA, frequency, and density values), and *DataSheet* (provides grids for tracking number of production trials and production accuracy for 21 sessions). Also available in the ScholarWorks supplement is a PowerPoint file (*2. AoAPic*) containing a corresponding picture for each target word, taken from https://pixabay.com/. I was unable to identify sufficient stimuli for / ð z / so there are no corresponding word sets for these targets. In addition, the set for / θ / was not weighted toward dense neighborhoods due to insufficient dense stimuli. This is highlighted in yellow in the Excel file. Taken together, the words selected for the following targets /k g f v s ʃ ʧ ʤ l r / faithfully replicate the procedures of Gierut and Morrisette, whereas the words selected for / θ / include slight departures from the procedures of Gierut and Morrisette.

In Gierut and Morrisette (2012a), children were seen two times weekly in 1-hr sessions. Production practice occurred in imitation until the child achieved 75% accuracy producing the treated sound in the treated words across two consecutive sessions or until a maximum of seven sessions had been completed. Spontaneous production then occurred until the child produced the treated sound in the treated words with 90% accuracy across three consecutive sessions or until a maximum of 12 sessions had been completed. Thus, the maximum number of sessions was 19. In the supplemental Excel file, data sheets are provided for 21 sessions, and an automatic summary of accuracy across sessions is provided at the bottom of the data sheet. On average, children in Gierut and Morrisette (2012a) achieved 110 responses per session in the imitation phase and 143 responses per session in the spontaneous phase. In the data sheet, 108–120 production attempts are highlighted as a reminder of the target intensity used in the studies establishing treatment efficacy. Clinician can depart from those methods to better meet the needs of a specific child and better fit the constraints of their clinical setting, but it would be important to monitor progress to ensure that modified methods are effective for the target child.

Lexicality (Real Word vs. Nonword)

Treatment Word Selection: Lexicality

"Lexicality" refers to the status of a sound sequence in a language, differentiating real words from nonwords. The prior discussion of the facilitatory effect of late-acquired words on sound learning assumed that the child knew the late-acquired word or was in the process of learning the late-acquired word. However, it is possible that children may not have even known the late-acquired words used in treatment. This raises the possibility that nonwords, which would be unknown by all children, could be more effective in phonological treatment than known words. This hypothesis was first tested by Gierut and colleagues (Gierut & Morrisette, 2010; Gierut, Morrisette, & Ziemer, 2010). In a retrospective examination of multiple single-subject studies, Gierut et al. (2010) examined learning of treated and untreated sounds for 60 children who had been taught sounds in either real words or nonwords. Results showed greater, more rapid sound change for children who were taught sounds in nonwords and gains were maintained posttreatment. In contrast, children who were taught sounds in real words made lesser and slower sound change but did eventually approximate the performance of the children in the nonword treatment 55 days after treatment was completed. In a prospective alternating treatment single-subject study by Gierut and colleagues (Gierut & Morrisette, 2010), children were taught two sounds: one in real words and one in nonwords. Learning of the treated sound during and following treatment was examined. Again, learning appeared to be more rapid initially for sounds taught in nonwords than in real words, but performance in the real word condition eventually reached a level similar to the nonword condition. The findings from Gierut and colleagues were further replicated by Cummings and Barlow (2011), who pitted nonwords against high-frequency real words in a multiple baseline single-subject study. Cummings and Barlow noted consistently strong learning across the two children treated in the nonword condition, whereas learning was variable for the two children in the real word condition with one of the children showing strong learning and the other demonstrating minimal sound change. Taken together, nonwords may facilitate phonological learning relative to real words, especially early in treatment.

Mechanism of Action: Lexicality

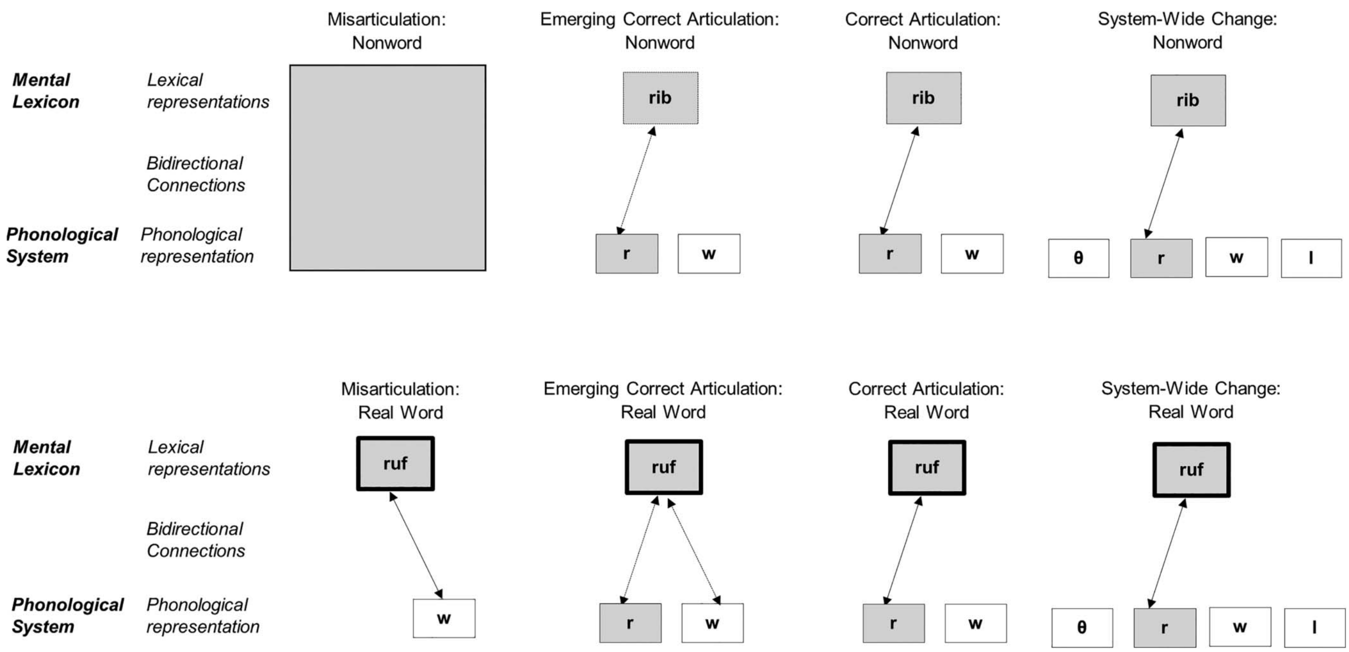
Nonwords may facilitate phonological learning because the word, the sound, and the connection between the two are all being learned simultaneously. As shown in the top first panel of Figure 4, there is no history of misarticulating the nonword "reeb" prior to the start of treatment. At the start of treatment in the top second panel of Figure 4, the child is exposed to the nonword with support for correct articulation. Thus, the child may create a new mental representation for the word, the target sound, and the connection between the two, potentially avoiding misarticulation as well as incorrect representations. Because an incorrect pattern does not have to be broken, this may facilitate faster learning of the treated sound as well as greater sound change overall, as shown in the top last panel of Figure 4 where additional new sounds (/θ l/) have been added to the phonological system. In contrast, the bottom first panel of Figure 4 shows that a child has a history of misarticulating a real word. Consequently, existing connections must be broken so that new connections can be established. This may slow learning of the treated sound and slow generalization, although a similar outcome may ultimately be achieved, as shown in the bottom last panel of Figure 4 where additional new sounds (/θ l/) have been added to the phonological system.

In summary, the mechanism of action for lexicality relates to whether an existing connection between a word and substituted sound must be broken before a new connection between a word and the correct sound is created. Note that this explanation provides continuity with the explanation of the effect of AoA. That is, both lexicality and AoA provide information about the existence (i.e., lexicality) or the strength (i.e., AoA) of a connection between a word and substituted sound.

Implementation Resource: Nonwords

To facilitate implementation of late-acquired words in clinical treatment of phonological disorders, I attempted to follow the procedures of Gierut and Morrisette (2010) to create a set of treatment words for six of the mid-8 consonants /k g f v ʧ ʤ/ (excluding / ŋ t /) and seven of the late-8 consonants / θ ð s z ʃ l r / (excluding / ʒ /). As with the other resources shared in this article, I attempted to identify six nonwords for each target sound. For reference, Gierut and Morissette used eight nonwords per sound, and Cummings and Barlow (2011) used five nonwords per sound. Thus, six nonwords are within the range used in past studies. I used the consonant–vowel–consonant (CVC) corpus created by Storkel (2013), which contains all legal CVCs in English and then categorizes the CVCs as real word or nonword based on whether or not the CVC occurred in a child or adult corpus. This differs slightly from the procedures of Gierut and Morrisette, who were comparing phonological treatment of real words versus nonwords. Thus, Gierut and Morrisette selected their real words first and then matched their nonwords to the real words by changing one or two sounds in the real word to create the nonword. I used the nonword CVC corpus of Storkel (2013) because it contained additional useful information. Specifically, the final consonants were coded in early-8, mid-8, and late-8 categories. The CVCs with early-8 final consonants were retained and those with mid-8 or late-8 consonants were deleted to ensure that the other consonants in the word would likely be correctly articulated by children in phonological therapy (Gierut & Morrisette, 2010). For each target sound, I attempted to select six CVCs with the following final consonants: one /p/, one /b/, one /d/, one /m/, two /n/. In this way, the final consonants in the set would consist of three bilabials, three alveolars, three stops, and three nasals. I also varied the vowels in the selected CVCs as much as possible to sample front/central/back and low/mid/high dimensions and avoided repeating vowels within the stimulus set for a given target sound. Gierut and Morrisette did not report explicit cutoffs for density. However, I computed the density for their nonword stimuli sets; on average, 42% of the words were high density (10+ neighbors based on the Hoosier Mental Lexicon) and 58% of the words were low density (nine or fewer neighbors based on the Hoosier Mental Lexicon). Note that Cummings and Barlow (2011) only used low-density stimuli in their study. I decided to select three high-density and three low-density CVCs for each target sound because there is not yet clear

Figure 4. Sequence of hypothesized changes that may occur during phonological treatment for the nonword "reeb" (/rib/) and the late-acquired word "roof" (/ruf/). Treated sounds and words are shaded.



evidence on how density might influence phonological learning when using nonwords in treatment.

Relevant materials in the ScholarWorks supplement include an Excel workbook entitled *3. NonwordList* consisting of several worksheets: *ReadMe* (provides a summary of how the nonwords were selected), *Klatt* (introduces the computer readable and searchable transcription system used), *NWs* (contains the list of nonwords for each target sound, including density based on the Hoosier Mental Lexicon), *Narrative* (contains a fillable nonword story), and *DataSheet* (provides grids for tracking number of production trials and production accuracy for 21 sessions). I was able to construct nonword sets following the outlined procedures for / g f v θ ð z ʃ ʧ ʤ l r /. For / k /, I departed from the stated procedures for final consonants due to the availability of low-density nonwords. The set for / k / contains two nonwords with / m / as the final consonant and only one nonword with / n / as the final consonant. This is highlighted in red font in the Excel worksheet. For / s /, I departed from the stated procedures for vowels due to the limited options for low-density nonwords. Here, I selected two nonwords that contained the vowel / aʊ /, which is highlighted in red font in the Excel worksheet.

Both Gierut and Morrisette (2010) and Cummings and Barlow (2011) assigned meanings to their nonwords and presented these meanings to the children via a story with corresponding pictures. The narrative was either read live (Cummings & Barlow, 2011) or a recorded version was played (Gierut & Morrisette, 2010) during each treatment session. To construct a story, pictures of less familiar objects were taken from https://pixabay.com/ and a narrative was created. Gierut and Morrisette's narratives presented each of the target nonwords twice, and the entire story was 120 words. Cummings and Barlow's narrative presented each of the target nonwords a variable number of times (from two to 11 times), and the entire story was 252 words. My narrative combined these two approaches and presented each target nonword five times, and the entire story was 246 words. Relevant materials in the ScholarWorks supplement include (a) a PowerPoint file (*3. NonwordPic*) containing the pictures for the story and for production practice during phonological treatment, (b) a Word file (*3. NonwordStory*) containing the narrative template for the story and an example nonword narrative, (c) the previously mentioned Excel file contains the meanings assigned to each nonword (*3. NonwordList, NWs* worksheet) and a worksheet to automatically create the narrative for each word set (*3. NonwordList, Narrative* worksheet), and (d) a video demonstrating pronunciation of the nonwords (*3. NonwordPronun*). Nonwords were pseudorandomly assigned a meaning so that low- and high-density nonwords alternated throughout the narrative to avoid all nonwords of one type clustering at the beginning or end of the narrative. These assignments are shown in an Excel file in the *NWs* worksheet. In that same file, there is a worksheet labeled *Narrative*. The selected nonword set from the *NWs* worksheet can be copied and pasted into the indicated area in the *Narrative* worksheet to autofill the nonwords into the narrative script.

Last, the Excel file (*3. NonwordList*) available in the ScholarWorks supplement contains a worksheet labeled *DataSheet*. This sheet copies the selected nonwords from the *Narrative* worksheet and associates them with their meaning and slide number for production practice. As with the other data sheets in the supplement, a grid is provided to tally correct and incorrect productions as well as number of production trials completed. Gierut and Morrisette (2010) reported that children in their study averaged 31 production attempts per condition per session. That is, an entire session would consist of approximately 31 production attempts for nonwords and 31 production attempts for real words, for a total of approximately 62 production attempts. For this reason, 30 and 60 production attempts are highlighted on the provided data sheet as potential targets for treatment intensity. Children in Cummings and Barlow (2011) achieved 110 production attempts in a session during the imitation phase and 143 production attempts in a session during the spontaneous phase of treatment. Based on this, 114 and 120 production attempts are also highlighted on the provided data sheet as a reminder of intensity.

As with the other studies reviewed, both Gierut and Morrisette (2010) and Cummings and Barlow (2011) use the already described criteria of 75% accuracy across two consecutive sessions or until a maximum of seven sessions in the imitation phase and 90% accuracy across three consecutive sessions or until a maximum of 12 sessions in the spontaneous phase. Thus, the maximum number of sessions for both studies was 19. Data sheets are provided for 21 sessions, and an automatic summary of accuracy across sessions is provided at the bottom of the data sheet. Finally, Gierut and Morrisette (2010) saw children three times per week in 1-hr sessions. Cummings and Barlow (2011) saw children two times per week in 1-hr sessions. As mentioned previously, clinician may need to depart from the procedures used to establish treatment efficacy. Careful monitoring of treatment progress is encouraged in these situations.

Discussion

Recent single-subject studies suggest that word characteristics are an active ingredient in phonological treatment. Consequently, clinicians have a variety of word selection strategies that may be effective in boosting phonological learning. Table 1 provides a summary of the word selection strategies that can be applied to 13 of the mid- and late-8 sounds, when the research methods from the treatment studies are followed closely. Moreover, implementation of this new active ingredient is made easier by using the implementation resources available in the accompanying supplemental materials on KU ScholarWorks. As shown in Table 1, several evidence-based word selection strategies are available for each sound. At present, there is not enough research to determine which of the options listed in Table 1 is the best of those available. Thus, clinicians should choose the word list that they deem most appropriate for a given child. For example, a clinician might be hesitant to use nonwords with a child who has a comorbid language disorder. Similarly, the late-acquired list might be avoided in that same situation, unless the child also needed to learn new vocabulary words and the late-acquired words were appropriate for that goal as well. Clearly, more research is needed to further understand how word characteristics can be further harnessed in clinical treatment to boost phonological learning. In addition, it is important to note that the evidence base demonstrating the effectiveness of word characteristics in facilitating learning in phonological treatment is still accruing, and thus, the highest level of evidence has not yet been reached. As with all treatment approaches, clinicians are encouraged to monitor client progress to ensure that appropriate gains are being made, and data collection worksheets are included in the supplemental materials to support this effort.

Turning to hypotheses concerning the mechanism of action of word characteristics, three distinct types of mechanisms were offered. First, it was argued that frequency and density affected the ease or difficulty in retrieving words from the lexicon and the ease or difficulty of holding words in working memory during therapy activities. In turn, it was hypothesized that when word retrieval or working memory was supported, greater language processing capacity was available to support new learning during phonological training. Second, it was reasoned that density relates to the number of opportunities to highlight how a sound is used in the words of the language by providing examples of the same sound in different words as well as contrasting different sounds in minimal pairs within the lexicon. It was assumed that this highlighting of how the sound functions in the language facilitated phonological learning. Finally, lexicality and AoA were claimed to indicate the existence (i.e., lexicality) or the strength (i.e., AoA) of a connection between the representation of a word in the mental lexicon and the representation of a sound in the phonological system. This information then relates to the likely need or difficulty in severing a connection between a word and sound to create a new connection between a word and a newly learned sound. These hypotheses concerning the mechanism of action of word characteristics warrant empirical validation.

The evidence demonstrating which characteristic is more influential when multiple characteristics are combined suggests that different characteristics or mechanisms of action may be the driving force in different contexts, rather than effects being additive. For example, when frequency and density are uncoupled, meaning one variable is held constant and the other is mixed, frequency (specifically high frequency) arises as the driving force in phonological change, suggesting the possibility that language processing is key in this context. In contrast, when frequency and density are coupled, meaning both variables are held constant, density (specifically high density) arises as the driving force in phonological change, suggesting that highlighting similarity and contrast of sounds in words is primary in this scenario. In terms of lack of additivity, high frequency combined with high density did result in the best outcome, but it was not substantially better than low frequency combined with high density. If the effects were additive, we would expect a

Table 1. Summary of implementation resources available for each target sound.

Target	Category	Frequency × Density	Frequency × AoA	Nonword
k	Mid-8	High frequency, high density	Low frequency, late AoA	Mixed density[a]
g	Mid-8	High frequency, high density	Low frequency, late AoA	Mixed density
f	Mid-8	High frequency, high density	Low frequency, late AoA	Mixed density
v	Mid-8	Low frequency, high density	Low frequency, late AoA	Mixed density
ʧ	Mid-8	Low frequency, high density	Low frequency, late AoA	Mixed density
ʤ	Mid-8	Low frequency, high density	Low frequency, late AoA	Mixed density
θ	Late-8	Low frequency, high density	Low frequency, late AoA[a]	Mixed density
ð	Late-8	High frequency, mixed density	N/A	Mixed density
s	Late-8	High frequency, high density	Low frequency, late AoA	Mixed density[a]
z	Late-8	Low frequency, high density	N/A	Mixed density
ʃ	Late-8	Low frequency, high density	Low frequency, late AoA	Mixed density
l	Late-8	High frequency, high density	Low frequency, late AoA	Mixed density
r	Late-8	High frequency, high density	Low frequency, late AoA	Mixed density

Note. AoA = age of acquisition.

[a]Slight departures from procedures described in published article or desirable features outlined in this article. Use with caution.

strong effect of frequency and clearer differentiation of low and high frequency within the high-density condition. In terms of the idea of a driving force, although frequency and ease of language processing may still be operating in the coupled condition, density has a stronger influence, emerging as the driving force in this situation. Finally, a similar pattern is observed when frequency and AoA are coupled; AoA (specifically late AoA) arises as the driving force in phonological change and the influence of frequency is absent. This pattern indicates that the strength of the lexical–phonological connection is vital in this condition. Examination of other combinations of characteristics, such as density and AoA or density and lexicality, would shed further light on how word characteristics and mechanisms of actions can be combined to facilitate phonological learning.

Acknowledgments

Katharine Kesler assisted in developing the clinical materials provided as part of this article.

References

Allen, M. M. (2013). Intervention efficacy and intensity for children with speech sound disorder. *Journal of Speech, Language, and Hearing Research, 56*(3), 865–877. https://doi.org/10.1044/1092-4388(2012/11-0076)

Ambridge, B., Kidd, E., Rowland, C. F., & Theakston, A. L. (2015). The ubiquity of frequency effects in first language acquisition. *Journal of Child Language, 42*(2), 239–273. https://doi.org/10.1017/S030500091400049X

Baker, E., & McLeod, S. (2011a). Evidence-based practice for children with speech sound disorders: Part 1. Narrative review. *Language, Speech, and Hearing Services in Schools, 42*(2), 102–139. https://doi.org/10.1044/0161-1461(2010/09-0075)

Baker, E., & McLeod, S. (2011b). Evidence-based practice for children with speech sound disorders: Part 2. Application to clinical practice. *Language, Speech, and Hearing Services in Schools, 42*(2), 140–151. https://doi.org/10.1044/0161-1461(2010/10-0023)

Barlow, J., & Gierut, J. A. (2002). Minimal pair approaches to phonological remediation. *Seminars in Speech and Language, 23*(1), 54–68.

Barry, C., Morrison, C. M., & Ellis, A. W. (1997). Naming the Snodgrass and Vanderwart pictures: Effects of age of acquisition, frequency and name agreement. *The Quarterly Journal of Experimental Psychology A: Human Experimental Psychology, 50A*(3), 560–585.

Baumeister, A. A. (1985). Age of acquisition and meaningfulness as predictors of word availability. *Journal of General Psychology, 112*(1), 109–112.

Beckman, M., & Pierrehumbert, J. (2004). Interpreting "phonetic interpretation" over the lexicon. In J. Local, R. Ogden, & R. Temple (Eds.), *Phonetic interpretation: Papers in laboratory phonology VI* (pp. 13–38). New York, NY: Cambridge University Press.

Bellon-Harn, M. L., Credeur-Pampolina, M. E., & LeBoeuf, L. (2013). Scaffolded-language intervention: Speech production outcomes. *Communication Disorders Quarterly, 34*(2), 120–132.

Bird, H., Franklin, S., & Howard, D. (2001). Age of acquisition and imageability ratings for a large set of words, including verbs and function words. *Behavior Research Methods, Instruments & Computers, 33*(1), 73–79.

Brandel, J., & Loeb, D. F. (2011). Program intensity and service delivery models in the schools: SLP survey results. *Language, Speech, and Hearing Services in Schools, 42*(4), 461–490. https://doi.org/10.1044/0161-1461(2011/10-0019)

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

Carroll, J. B., & White, M. N. (1973). Age-of-acquisition norms for 220 picturable nouns. *Journal of Verbal Learning & Verbal Behavior, 12*(5), 563–576.

Cirrin, F. M. (1984). Lexical search speed in children and adults. *Journal of Experimental Child Psychology, 37*(1), 158–175.

Cummings, A. E., & Barlow, J. A. (2011). A comparison of word lexicality in the treatment of speech sound disorders. *Clinical Linguistics & Phonetics, 25*(4), 265–286. https://doi.org/10.3109/02699206.2010.528822

Curtin, S., & Zamuner, T. S. (2014). Understanding the developing sound system: Interactions between sounds and words.

Wiley Interdisciplinary Reviews-Cognitive Science, 5*(5), 589–602. https://doi.org/10.1002/wcs.1307

Dinnsen, D. A. (2002). *A reconsideration of children's phonological representations*. Paper presented at the the 26th annual Boston University Conference on Language Development, Somerville, MA.

Dinnsen, D. A., O'Connor, K. M., & Gierut, J. A. (2001). The puzzle-puddle-pickle problem and the Duke-of-York gambit in acquisition. *Journal of Linguistics, 37,* 503–525.

Edwards, J., Munson, B., & Beckman, M. E. (2011). Lexicon-phonology relationships and dynamics of early language development—A commentary on Stoel–Gammon's "Relationships between lexical and phonological development in young children." *Journal of Child Language, 38*(1), 35–40. https://doi.org/10.1017/s0305000910000450

Gerhand, S., & Barry, C. (1998). Word frequency effects in oral reading are not merely age-of-acquisition effects in disguise. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 24*(2), 267–283. https://doi.org/10.1037/0278-7393.24.2.267

Gierut, J. A. (1989). Maximal opposition approach to phonological treatment. *Journal of Speech and Hearing Disorders, 54*(1), 9–19.

Gierut, J. A. (1990). Differential learning of phonological oppositions. *Journal of Speech and Hearing Research, 33*(3), 540–549.

Gierut, J. A. (1991). Homonymy in phonological change. *Clinical Linguistics & Phonetics, 5,* 119–137.

Gierut, J. A. (2001). Complexity in phonological treatment: Clinical factors. *Language, Speech, and Hearing Services in Schools, 32*(4), 229–241. https://doi.org/10.1044/0161-1461(2001/021)

Gierut, J. A. (2007). Phonological Complexity and Language Learnability. *American Journal of Speech-Language Pathology, 16*(1), 6–17. https://doi.org/10.1044/1058-0360(2007/003)

Gierut, J. A. (2016). Nexus to lexis: Phonological disorders in children. *Seminars in Speech and Language, 37*(4), 280–290. https://doi.org/10.1055/s-0036-1587704

Gierut, J. A., & Dale, R. A. (2007). Comparability of lexical corpora: Word frequency in phonological generalization. *Clinical Linguistics & Phonetics, 21*(6), 423–433.

Gierut, J. A., & Dinnsen, D. A. (1986). On word-initial voicing: Converging sources of evidence in phonologically disordered speech. *Language and Speech, 29*(2), 97–114.

Gierut, J. A., & Morrisette, M. L. (2010). Phonological learning and lexicality of treated stimuli. *Clinical Linguistics & Phonetics, 24*(2), 122–140.

Gierut, J. A., & Morrisette, M. L. (2012a). Age of word acquisition effects in treatment of children with phonological delays. *Applied Psycholinguistics, 33*(1), 121–144.

Gierut, J. A., & Morrisette, M. L. (2012b). Density, frequency and the expressive phonology of children with phonological delay. *Journal of Child Language, 39*(4), 804–834. https://doi.org/10.1017/S0305000911000304

Gierut, J. A., Morrisette, M. L., & Champion, A. H. (1999). Lexical constraints in phonological acquisition. *Journal of Child Language, 26*(2), 261–294.

Gierut, J. A., Morrisette, M. L., & Dickinson, S. L. (2015). Effect size for single-subject design in phonological treatment. *Journal of Speech, Language, and Hearing Research, 58*(5), 1464–1481. https://doi.org/10.1044/2015_JSLHR-S-14-0299

Gierut, J. A., Morrisette, M. L., & Ziemer, S. M. (2010). Nonwords and generalization in children with phonological disorders. *American Journal of Speech-Language Pathology, 19*(2), 167–177. https://doi.org/10.1044/1058-0360(2009/09-0020)

Gilhooly, K. J., & Gilhooly, M. L. (1980). The validity of age-of-acquisition ratings. *British Journal of Psychology, 71*(1), 105–110.

Gilhooly, K. J., & Logie, R. H. (1980). Age-of-acquisition, imagery, concreteness, familiarity, and ambiguity measures for 1,944 words. *Behavior Research Methods & Instrumentation, 12*(4), 395–427.

Hirsh, K. W., & Ellis, A. W. (1994). Age of acquisition and lexical processing in aphasia: A case study. *Cognitive Neuropsychology, 11,* 435–458.

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

Locke, J. L. (1979). Homonymy and sound change in the child's acquisition of phonology. In N. Lass (Ed.), *Speech and language: Advances in basic research and practice* (Vol. 2, pp. 257–282). New York, NY: Academic Press.

Locke, J. L. (1980). The inference of speech perception in the phonologically disordered child, Part II: Some clinically novel procedures, thier use, some findings. *Journal of Speech and Hearing Disorders, 45,* 445–468.

Macken, M. A. (1980). The child's lexical representation: The 'puzzle-puddle-pickle' evidence. *Journal of Linguistics, 16,* 1–17.

Maxwell, E. M. (1984). On determining underlying phonological representations of children: A critique of current theories. In M. Elbert, D. A. Dinnsen, & G. Weismer (Eds.), *Phonological theory and the misarticulating child* (ASHA Monographs No. 22, pp. 18–29). Rockville, MD: ASHA.

Maxwell, E. M., & Weismer, G. (1982). The contribution of phonological, acoustic and perceptual techniques to the characterization of a misarticulating child's voice contrast for stops. *Applied Psycholinguistics, 3,* 29–43.

McGregor, K. K., & Schwartz, R. G. (1992). Converging evidence for underlying phonological representations in a child who misarticulates. *Journal of Speech and Hearing Research, 35,* 596–603.

Metsala, J. L., & Walley, A. C. (1998). Spoken vocabulary growth and the segmental restructuring of lexical representations: Precursors to phonemic awareness and early reading ability. In J. L. Metsala & L. C. Ehri (Eds.), *Word recognition in beginning literacy* (pp. 89–120). Hillsdale, NJ: Erlbaum.

Morrisette, M. L., & Gierut, J. A. (2002). Lexical organization and phonological change in treatment. *Journal of Speech, Language, and Hearing Research, 45,* 143–159.

Munson, B., Edwards, J., Schellinger, S. K., Beckman, M. E., & Meyer, M. K. (2010). Deconstructing phonetic transcription: Covert contrast, perceptual bias, and an extraterrestrial view of Vox Humana. *Clinical Linguistics & Phonetics, 24*(4–5), 245–260. https://doi.org/10.3109/02699200903532524

Munson, B., Johnson, J. M., & Edwards, J. (2012). The role of experience in the perception of phonetic detail in children's speech: A comparison between speech-language pathologists and clinically untrained listeners. *American Journal of Speech-Language Pathology, 21*(2), 124–139. https://doi.org/10.1044/1058-0360(2011/11-0009)

Munson, B., Schellinger, S. K., & Urberg, K. (2012). Measuring speech-sound learing using visual analog scaling. *SIG 1 Perspectives on Language Learning and Education, 19,* 19–30.

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

Powell, T. W. (1991). Planning for phonological generalization: An approach to treatment target selection. *American Journal of Speech-Language Pathology, 1,* 21–27.

Rinsland, H. D. (1949). *The basic vocabulary of elementary school children*. New York, NY: Macmillan.

Roodenrys, S., & Hinton, M. (2002). Sublexical or lexical effects on serial recall of nonwords? *Journal of Experimental Psychology: Learning, Memory, and Cognition, 28*(1), 29–33.

Snodgrass, J. G., & Yuditsky, T. (1996). Naming times for the Snodgrass and Vanderwart pictures. *Behavior Research Methods, Instruments and Computers, 28,* 516–536.

Stoel-Gammon, C. (2011). Relationships between lexical and phonological development in young children. *Journal of Child Language, 38*(1), 1–34. https://doi.org/10.1017/s0305000910000425

Storkel, H. L. (2002). Restructuring of similarity neighbourhoods in the developing mental lexicon. *Journal of Child Language, 29*(2), 251–274.

Storkel, H. L. (2004). The emerging lexicon of children with phonological delays: Phonotactic constraints and probability in acquisition. *Journal of Speech, Language, and Hearing Research, 47*(5), 1194–1212.

Storkel, H. L. (2013). A corpus of consonant–vowel–consonant real words and nonwords: Comparison of phonotactic probability, neighborhood density, and consonant age of acquisition. *Behavior Research Methods, 45*(4), 1159–1167. https://doi.org/10.3758/s13428-012-0309-7

Storkel, H. L., & Hoover, J. R. (2010). An online calculator to compute phonotactic probability and neighborhood density on the basis of child corpora of spoken American English. *Behavior Research Methods, 42*(2), 497–506.

Storkel, H. L., Maekawa, J., & Aschenbrenner, A. J. (2013). The effect of homonymy on learning correctly articulated versus misarticulated words. *Journal of Speech, Language, and Hearing Research, 56*(2), 694–707. https://doi.org/10.1044/1092-4388(2012/12-0122)

Thomson, J. M., Richardson, U., & Goswami, U. (2005). Phonological similarity neighborhoods and children's short-term memory: Typical development and dyslexia. *Memory & Cognition, 33*(7), 1210–1219. https://doi.org/10.1037/0278-7393.28.1.29

Thorn, A. S. C., & Frankish, C. R. (2005). Long-term knowledge effects on serial recall of nonwords are not exclusively lexical. *Journal of Experimental Psychology, 31*(4), 729–735.

Turkstra, L. S., Norman, R., Whyte, J., Dijkers, M. P., & Hart, T. (2016). Knowing what we're doing: Why specification of treatment methods is critical for evidence-based practice in speech-language pathology. *American Journal of Speech-Language Pathology, 25*(2), 164–171. https://doi.org/10.1044/2015_AJSLP-15-0060

Turner, J. E., Valentine, T., & Ellis, A. W. (1998). Contrasting effects of age of acquisition and word frequency on auditory and visual lexical decision. *Memory and Cognition, 26,* 1282–1291.

Tyler, A. A., Edwards, M. L., & Saxman, J. H. (1990). Acoustic validation of phonological knowledge and its relationship to treatment. *Journal of Speech and Hearing Disorders, 55,* 251–261.

Vihman, M. M. (1982). A note on children's lexical representations. *Journal of Child Language, 9,* 249–253.

Vihman, M. M. (2017). Learning words and learning sounds: Advances in language development. *British Journal of Psychology, 108*(1), 1–27. https://doi.org/10.1111/bjop.12207

Walley, A. C., Metsala, J. L., & Garlock, V. M. (2003). Spoken vocabulary growth: Its role in the development of phoneme awareness and early reading ability. *Reading and Writing, 16*(1–2), 5–20.

Webster's Seventh Collegiate Dictionary. (1967). Los Angeles, CA: Library Reproduction Service.

Weismer, G., Dinnsen, D., & Elbert, M. (1981). A study of the voicing distinction associated with omitted, word-final stops. *Journal of Speech and Hearing Disorders, 46,* 320–328.

Werker, J. F., & Curtin, S. (2005). PRIMIR: A developmental framework of infant speech processing. *Language Learning and Development, 1*(2), 197–234.

Williams, A. L. (2012). Intensity in phonological intervention: Is there a prescribed amount? *International Journal of Speech-Language Pathology, 14*(5), 456–461. https://doi.org/10.3109/17549507.2012.688866