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How to Meet the Neighbors: Modality Effects on Phonological Generalization

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Abstract

Long-term auditory priming of words from dense neighborhoods has been posited as a learning mechanism that affects change in the phonological structure of children's lexical representations. An apparent confound associated with the modality of priming responsible for structural change has been introduced in the literature, which challenges this proposal. Thus, our purpose was to evaluate prime modality in treatment of children with phonological delay. Nine children were assigned to auditory-visual, auditory or visual priming of words from dense neighborhoods prior to treatment of production as the independent variable. The dependent variable was phonological generalization. Results showed that auditory priming (with or without visual input) promoted greater generalization on an order of magnitude of 3:1. Findings support the theoretical significance of auditory priming for phonological learning and demonstrate the applied utility of priming in clinical treatment.

It has long been thought that children acquire language from the input (Jakobson, 1941/1968), but two recent innovations have clarified this view. A first is that statistical regularities in the input support a child's discovery of patterns and symmetries in language structure (Aslin, Saffran, & Newport, 1999). Regularities that affect language learning include, for example, the frequency of word occurrence, commonality of sounds and sound sequences and age-of-word-acquisition (Stoel-Gammon, 2011). By all accounts, regularities in the input are a bootstrap to children's acquisition of language. A second innovation establishes how a child's attention to statistical regularities of the input leads to abstract knowledge of linguistic structure. Here, one thought is that repeated exposure to systematicities in the input is a naturalistic case of long-term auditory word priming, such that priming is hypothesized as a learning mechanism that drives the acquisition process (Church & Fisher, 1998).

In this paper, we consider these proposals in the context of phonological acquisition by children with phonological delay (PD). These children were of interest because they require treatment to promote phonological learning. Treatment, in turn, may be experimentally

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Declaration of Interests

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designed to expose a child to input regularities by using a protocol that entails long-term auditory word priming. On the side of theory, our goal was to evaluate the effects of prime modality on phonological generalization as a test of the more general hypotheses outlined above. On the side of application, the goal was to evaluate the efficacy of stimulus presentation in the design of clinical treatment. By way of background, we begin with a definition of priming and its observed effects on language learning generally. We then describe an innovative priming methodology that holds promise for use in treatment of PD; however, in its prior applications, a potential confound was introduced, thus motivating the present study.

Priming and Language Learning

Priming is an experimental paradigm that involves the presentation of a set of experimental stimuli similar to a set of test stimuli so as to facilitate a behavioural response (Zwitsers, 1997). The adult literature is replete with reports of the effects of priming on linguistic structure (Bock, Dell, Chang, & Onishi, 2007; Ferreira & Bock, 2006). Comparable demonstrations have emerged for children, including those with (Leonard, Miller, Grela, Holland, Gerber, & Petucci, 2000) and without language learning disorders (Brooks & MacWhinney, 2000; Savage, Lieven, Theakston, & Tomasello, 2003). In general, results show that, when abstract linguistic structure is primed, use of that structure in comprehension and expression is enhanced (Ferreira & Bock, 2006). Priming also promotes generalization to related, but nonidentical structures (Vasilyeva & Waterfall, 2012) and further, the effects of priming are maintained over time (Savage, Lieven, Theakston, & Tomasello, 2006). The consensus is that priming triggers implicit language learning because the beneficial effects take place rapidly, automatically and continuously across the lifespan (Ferreira & Bock, 2006). Moreover, when used for instructional purposes, priming provides the platform from which the internal representation of linguistic structure may be changed, modified or elaborated by the learner (Savage et al., 2006).

With this backdrop, Church and Fisher (1998) advanced long-term auditory word priming as a learning mechanism for lexical and phonological acquisition. They surmised that priming plays a dual role in the encoding of words for purposes of lexical learning and in reinforcing the representation of the sound patterns of those words for purposes of phonological learning. They reasoned that priming provides the essential experiences needed to construct a mental representation of words. This followed from their observation that priming allows a child to detect contextual variability in the input, discern similarities in the phonological form of words and isolate phonological differences between words that are seemingly alike. To establish the validity of the proposal, Church and Fisher (1998) evaluated children's perceptual recognition of novel words. In a series of studies, they demonstrated that by age 2, children more accurately recognized novel words that were primed compared to words that were not. The effects were independent of meaning and attributed instead to a child's representation of the sound patterns of words, thereby underscoring the phonological benefits that accrue from priming.

If priming solidifies the representation of sound patterns in words as suggested, then it may be ideally suited for children with PD. A primary characteristic of PD is a reduced

consonantal inventory relative to the input language (Dinnsen, Chin, Elbert & Powell, 1990; Gierut, Simmerman, & Neumann, 1994). Children with PD tend to use nasals, stops and glides to the exclusion of other sounds, resulting in the merger of phonemic distinctions, homonymy and unintelligibility. The cause of the disorder is unknown, but some speculate that the problem lies in the nature of children's underlying representations of words (Macken, 1980; Stoel-Gammon, 2011). This view is consistent with linguistic accounts of phonological acquisition, which argue that development of the sound system occurs through change (Dinnsen, 1984), elaboration (Rice & Avery, 1995) and/or reorganization (Gnanadesikan, 1996) of the phonological content of lexical representations. In the case of PD, direct treatment is required to affect such advances and priming be a way to achieve the intended effect. Given the potential promise, a key consideration is how to best incorporate priming in treatment. For this, we turn to the word learning literature for insight.

A Methodology

Two complementary studies employed priming for lexical learning. Merriman and Marazita (1995) evaluated toddlers' ability to assign meaning to novel nouns, whereas Demke, Graham, and Siakaluk (2002) evaluated preschoolers' ability to label novel nouns. In both studies, novel nouns to be learned were first primed, with the prediction that priming would facilitate the anticipated behavioural response.

Words from dense lexical neighborhoods were used as primes so as to emphasize a known regularity of the input. A dense neighborhood consists of many phonetically similar sounding words based on 1-phoneme substitutions, deletions or additions (Luce, 1986). Dense neighborhoods are germane to word learning because children build the lexicon by first acquiring words that overlap in phonological form (Jusczyk, Luce, & Charles-Luce, 1994). In this way, prior studies of word learning capitalized on the dual advantage of dense neighborhoods as a statistical regularity of the input and priming as a mechanism of learning.

A similar methodology was used across studies. Priming was delivered using stories that read much like a Dr. Seuss book, with one story for each novel noun to be learned. Each story was visually depicted and there were approximately 10 exposures to prime words from dense neighborhoods. Primes always shared the same rhyme as the novel noun to be learned, e.g. 'cane, rain, chain' were embedded in a story to prime the novel noun 'tane' (Demke et al., 2002). Hence, rhyme priming was employed.

In prime delivery, a child listened to stories while viewing corresponding pictures. No behavioural response was required consistent with implicit learning. After priming, instruction on the novel nouns commenced, with a child's response in keeping with the experimental intent. In Merriman and Marazita (1995), a child pointed to visual referents of novel nouns and in Demke et al. (2002), a child imitated novel nouns.

Results were mixed. On the one hand, Merriman and Marazita (1995) found that priming words from dense neighborhoods facilitated lexical learning, consistent with Church and Fisher's (1998) hypothesis. On the other hand, Demke et al. (2002) found that words from

dense neighborhoods helped lexical learning, but only when these items were presented after instruction. Thus, timing of exposure to words from dense neighborhoods (i.e. before or after instruction) is an open issue relative to word learning.

This notwithstanding, the prior studies of word learning are relevant to our interest in phonological learning for at least two reasons. An innovative and developmentally appropriate methodology for long-term auditory word priming was put forth, which has promise for use in treatment of PD. However, that method also introduced a possible confound, which clouds the evaluation of priming as a mechanism of learning.

Promise and Paradox

As extended to phonological treatment, the priming method has several attractive components. One is the use of words from dense neighborhoods as primes. Dense neighborhoods are relevant to phonological learning, with production accuracy (Sosa & Stoel-Gammon, 2012), phonemic distinctiveness (Stoel-Gammon, 2011; Zamuner, Gerken, & Hammond, 2004) and phonological generalization (Gierut & Morrisette, 2012b) all being attributed to dense structure. It has further been suggested that the phonological similarity of words in dense neighborhoods makes it easier for a child to imitate those forms (Merriman & Marazita, 1995); indeed, studies of PD have demonstrated this effect (Beckman & Edwards, 2000). Moreover, imitation has long been part of (Van Riper, 1978), and implicated in the success of phonological treatment (Dean, Howell, Waters, & Reid, 1995).

Another positive element of priming is its magnification of phonemic contrasts (Merriman & Marazita, 1995). When a child repeatedly hears words from dense neighborhoods, segmental overlaps habituate and points of uniqueness are brought to the forefront. For example, repeated exposure to ‘cane, rain, chain’ forces the rhyme to recede and places emphasis instead on the onset. Notice too that the segments in onset position signal phonemic contrasts. This is relevant because children with PD are prone to collapses of contrast as a consequence of their reduced consonantal inventories.

The method of priming also provides for the occurrence of minimal pairs. These are affiliated with each other in stories and the treatment that follows introduces yet another word of the same minimal pair set. It has long been known that children with PD are highly responsive to minimal pair treatment (Baker & McLeod, 2011) and priming may offer another way to expose a child to minimal pairs. Priming further provides for massed auditory input prior to treatment, as in the spirit of auditory bombardment (Van Riper, 1978). Auditory bombardment is often a component of phonological treatment, but its efficacy has not been empirically established (Pollack & LaLonde, 1989).

To our knowledge, there is one report of priming in treatment of PD (Gierut & Morrisette, 2013). That work extended the priming method above, such that children were exposed to stories consisting of words from dense neighborhoods at the start of each treatment session. Following exposure, they were then taught to produce a sound excluded from their consonantal inventory in the initial position of words. The words that were treated were either neighbors of the primes or unrelated items. Results showed greater phonological generalization when dense neighbors of treated words were primed. This effect was

consistent with Merriman and Marazita's (1995) data from lexical learning and demonstrated that the methodology was equally applicable to phonological learning and clinical treatment. It also provided support for Church and Fisher's (1998) hypothesis that long-term auditory word priming dually affects lexical and phonological learning.

There is one caveat, however, that is evident in the priming method. Specifically, the method developed by Merriman and Marazita (1995) and Demke et al. (2002) exposed children to words in stories, but the stories themselves were visually depicted. The same was true in the phonological extension of the procedure. Consequently, it is not clear whether the benefits of priming are due solely to auditory input, yet this is the central premise of Church and Fisher's (1998) hypothesis. Thus, the purpose of this study was to disentangle the effects of modality when words from dense neighborhoods were primed in treatment of children with PD. It was expected that the results would clarify the theoretical position and inform clinical extensions of priming to PD.

Methods

Participants and Their Phonologies

Nine preschool children with PD (mean age 4;6) were recruited by public announcement. To participate, a child scored 1 standard deviation below the normative mean on the *Goldman-Fristoe Test of Articulation-2* (Goldman & Fristoe, 2000) and produced at least 6 sounds in error on this measure across phonetic contexts. Inclusionary criteria required performance within typical limits on a battery of diagnostic tests (Gierut, 2008b) that included hearing acuity, oral-motor structure/function, nonverbal intelligence, expressive/receptive language, expressive/receptive vocabulary and working memory. Exclusionary criteria were literacy, bilingualism and concurrent speech treatment.

Children who met these criteria contributed a detailed speech sample. An established probe consisting of 293 words (Gierut, 2008b) was used to elicit production of all English consonants in all relevant word positions in multiple exemplars. The probe provided for elicitation of minimal pairs as evidence of the contrastive (phonemic) status of sounds in a child's inventory. The probe was administered using a spontaneous picture-naming task and a child's responses were digitally recorded. A trained listener, blind to the experiment, phonetically transcribed the data and reliability was established as reported below.

Probe data were used to identify the inventory of sounds a child used phonemically, along with corresponding exclusions. Sounds excluded from the inventory were of interest because these were manipulated in treatment and measured as evidence of phonological generalization. Established criteria were applied to identify sounds excluded, i.e. near 0% accuracy of probe production across contexts in conjunction with an absence of minimal pairs (Gierut & O'Connor, 2002). Characteristics of children who participated are shown in table 1.

Experimental Design and Variables

A single-subject staggered multiple-baseline across subjects design was used, with the number of baselines increasing by 1 as successive children enrolled. The premise is that

baseline performance will remain stable until the instatement of treatment so as to establish a cause-effect relationship between teaching and learning.

As implemented herein, the baseline was obtained through repeated administrations of the aforementioned probe. Following baseline, children were pseudorandomly assigned to 1 of 3 experimental conditions: auditory-visual versus auditory versus visual priming of words from dense neighborhoods prior to treatment on production of a sound excluded from the inventory. Visual priming was intended as the control condition to Church and Fisher's (1998) hypothesis because auditory input was withheld. Thus, the independent variable was modality of priming, with three replications (children) per experimental condition.

The dependent variable was generalization to treated and untreated sounds excluded from children's phonemic inventories. Generalization was operationalized as the percent accuracy of production relative to baseline. It was measured using the probe, with procedures for elicitation, transcription and reliability as previously described. Generalization was sampled on a variable schedule of two sessions, starting at baseline and continuing to completion of treatment.

Stimuli

Two sets of stimuli were developed for use in priming and in treatment. Stimuli used in treatment are described first because their form dictated which words could serve as primes.

Treated stimuli—Six words were chosen for treatment based on three criteria: (1) words were from dense neighborhoods comprised of 10 or more neighbors (Luce, 1986; retrieved from <http://neighborhoodsearch.wustl.edu>), (2) to the extent possible, they were 3 segments in length (CVC), and (3) the sound that was treated was in the initial position of the word. There was a general effort to choose words familiar to children based on age-of-word-acquisition norms (Bird, Franklin, & Howard, 2001; Gilhooly & Logie, 1980). There were also efforts to equate log frequency (retrieved from <http://neighborhoodsearch.wustl.edu>) and phonotactic probability (retrieved from <http://www.people.ku.edu/~mvitev/PhonoProbHome.html>) of the treated words. Characteristics of treated words are reported in table 2, with samples shown in the appendix.

Prime stimuli—Forty-eight words were identified as primes (appendix). These were neighbors of the treated words in that they had the same rhyme. Primes met the same criteria as the treated words, with one exception: primes did not include the treated sound in the initial position. Otherwise, primes were from dense neighborhoods, 3 segments in length (as possible), familiar to children and equated in log frequency and phonotactic probability (table 2).

Prime words and treated words were comparable in their characteristics. Following from table 2, there was no significant difference between the stimulus sets based on age-of-word-acquisition, $t(98) = 0.43, p = .67$; log frequency, $t(160) = 1.12, p = .26$; sum of segment frequency, $t(160) = 1.87, p = .06$; or sum of biphone frequency $t(160) = 0.54, p = .59$.

Materials

Two sets of materials were developed for use in priming and in treatment. These were kept distinct in the experimental sessions.

Priming materials—Six stories were created (appendix) in keeping with the methods of Merriman and Marazita (1995) and Demke et al. (2002). There was one story for each of the six treated words. Stories averaged 34 words in length. A female talker recorded each story in a speaking style typical of reading to young children. Stories averaged 13.2s in duration, with a 2.1s ISI between stories. Illustrations of the stories were created, measuring 7.5×10 inches. These materials were assembled into Powerpoint for random presentation at the start of each treatment session.

Treatment materials—Pictures were used to elicit a child's responses during treatment (Shriberg, Kwiatkowski, & Snyder, 1990). These were retrieved from Google images with one picture for each treated word. Pictures were arranged in Powerpoint for random presentation during treatment. Treatment materials were never shown during priming and vice versa.

Procedures

Experimental sessions were 1-hour in length, three times weekly. Each session consisted of two sequentially ordered phases: priming followed by treatment on sound production.

Priming—A child was seated at a small table in a quiet room of an experimental suite. A desktop computer with 17-inch display and 2 desktop speakers were on the table. At the start of each session, a child was instructed to attend; no verbal, physical or other response was required. In the auditory-visual condition, a child heard the prime stories while viewing corresponding pictures. In the auditory condition, a child heard the stories without seeing pictures. In the visual control condition, a child saw only the pictures without hearing stories.

Treatment—After priming, treatment on sound production was initiated. Each child was taught one sound excluded from, and specific to his/her phonemic inventory. Treated sounds were restricted to the 'late-8' consonants /l/, /r/ or /s/ (Shriberg, Kwiatkowski, & Gruber, 1994) because these are commonly in error in typical and delayed populations. Within each experimental condition, one child was taught /l/, one /r/ and one /s/. Treating different sounds within and across conditions is intended to minimize sound-specific learning effects while maximizing child-specific benefits (Rvachew & Nowak, 2001; Tyler, Edwards, & Saxman, 1987).

An established protocol of imitation followed by spontaneous production was used (Gierut, 2008a). During imitation, a child was shown pictures of the treated words. The experimenter modeled each word and a child imitated. 1:1 feedback was provided about accuracy of production, with praise for accurate outputs and placement cues for erred outputs. Imitation continued until a child achieved 75% accurate production over two consecutive sessions or until seven total sessions were completed, whichever occurred first. Treatment then shifted

to spontaneous production and a child produced the treated sound in treated words without a preceding model. Feedback was provided as in imitation. Spontaneous treatment continued until a child achieved 90% accuracy of production over three consecutive sessions or until 12 total sessions were completed, whichever occurred first.

Reliability

Transcription reliability was established for 10% of probe data collected from each child. Two phonetically trained and blinded judges independently transcribed the samples, and these were compared point-to-point for consonant agreement. Reliability was established at 93% mean agreement (range: 85–98%).

Fidelity was assessed for 3% of the experimental sessions using a checklist procedure (Gierut, 2008a). An independent observer monitored randomly selected sessions to ensure that the protocol was administered as directed and probe data sampled as scheduled. The experimenter was blind to the collection of fidelity data. Fidelity was established at 100%.

Results

Two kinds of data were evaluated: learning during treatment and generalization. Learning during treatment established that children learned what had been taught as the foundation from which differential generalization could occur as the primary dependent variable.

Learning During Treatment

Table 3 summarizes the data associated with session-by-session time and performance during treatment. It can be seen that the auditory-visual condition required an average of 15 sessions to complete, the auditory condition, 11 sessions and the visual condition, 13 sessions. There was no significant difference in the number of sessions in imitation and spontaneous training across conditions, $\chi^2(2, N=6) = 0.05, p = .98$.

Performance during treatment was also comparable across conditions (table 3). Children achieved 72–85% mean accuracy in imitation and 84–97% accuracy in spontaneous production of the treated sound in treated words. Independent nonparametric McNemar tests for the significance of change established that learning during treatment under each condition was statistically reliable, where $p < .001$. This demonstrated that gains in production accuracy during treatment were not due to chance. It further showed that, regardless of experimental assignment, treatment provided children with an equal footing from which they were then free to generalize as the principal dependent variable.

Generalization

Recall that generalization was defined as production accuracy of sounds excluded from children's phonemic inventories relative to baseline and sampled longitudinally on the probe. These data were evaluated using conventional procedures (Bothe & Richardson, 2011) of description, significance and magnitude of gain as benchmarks for interpretation.

Figure 1 plots the generalization curves associated with each experimental condition. Key points in time are depicted, representing the aggregated baseline, generalization at the

completion of imitation and also, spontaneous training. By visual inspection, there was a gradient of generalization, such that auditory-visual > auditory > visual priming. Notice that the two auditory priming conditions resulted in greater transfer than the visual control.

An established criterion cut-off of 10% gain relative to baseline was applied in descriptive evaluation of these data (Elbert, Dinnsen, & Powell, 1984). The cut-off is used to binarily code experimental conditions as inducing 'yes/no' generalization, as in table 4. Consistent with visual inspection, auditory-visual and auditory priming met the 10% cut-off, but visual priming did not.

The McNemar test of the significance of change was applied to determine whether generalization of the treated sound to untreated words and contexts was statistically reliable for each independent condition. Table 4 shows that generalization in the auditory-visual and auditory priming conditions was not due to chance, $p = .008$ and $< .001$ respectively. By comparison, generalization associated with visual priming was not statistically reliable, $p = .219$. This is notable because all three priming conditions led to reliable gains during treatment: production accuracy of the treated sound in the treated context of treated words improved. However, only the auditory-visual and auditory conditions triggered generalization of the treated sound to new lexical items and word positions.

Effect size was computed as an estimate of the magnitude of generalization associated with each independent condition. Standard mean difference with correction for continuity (Gierut & Morrisette, 2011) was applied for consistency with other small-n treatment studies (Gierut & Morrisette, 2012a; b; 2013; see also Beeson & Robey, 2006). This statistic is specific to single-subject design (Busk & Serlin, 1992) and not to be confused with effect size for large-N studies (Cohen, 1988). Standard mean difference with correction for continuity is calculated in the following way: Mean accuracies are computed for sounds excluded from the phonemic inventory of each child at baseline for each experimental condition. Likewise, mean accuracies are computed for generalization to the completion of treatment as causal to each condition. The difference between mean baseline and generalization data is then divided by the mean standard deviation of the baseline for the population (i.e. all participating children) to yield an effect size, d . The standard deviation of the population takes into account variability in baseline performance (Glass, 1977) and 0% baselines in computation of effect size (Gierut & Morrisette, 2011). In this study, the standard deviation of the baseline for the population was 0.015.

Table 4 shows effect sizes associated with each condition, where $d = 7.92$ for auditory-visual priming, 7.04 for auditory priming, 2.77 for visual priming. Absolute d values mirrored the gradient of generalization seen in figure 1, such that the two auditory priming conditions were affiliated with greater transfer. The magnitude of generalization gain associated with the auditory conditions was on the order of 3:1 relative to the visual control. It should be cautioned that the magnitude of gain due to auditory-visual versus auditory priming should not yet be definitively ranked. The difference in absolute d values for these conditions was modest (cf. $d = 7.92$ vs. 7.04, respectively). Moreover, auditory-visual priming was not a linear combination that further boosted generalization. That is, the d value for auditory-visual priming did not equal the sum of the combined d values for auditory +

visual priming alone ($7.92 \neq 7.04 + 2.77$). Thus, a conservative interpretation is that auditory priming (with or without pictures) was more efficacious than the visual control in inducing phonological generalization.

Discussion

This study set out to examine the effects of prime modality on phonological generalization by children with PD enrolled in treatment. Together, the results of visual inspection and binary coding of generalization curves, statistical evaluation of change and effect size estimates of magnitude of gain converged on the efficacy of auditory priming for phonological learning. The relevance is three-fold: theoretical—in testing the hypothesis that auditory priming functions as a mechanism of learning, methodological—in disentangling an apparent confound in prior priming applications and clinical—in evaluating priming as a potential teaching tool. While preliminary, the results have implications for all three perspectives and present new opportunities for continued study.

Theoretical Implications

The present study adds to the literature that evaluated priming as a mechanism of learning using words from dense neighborhoods as a bootstrap. Collectively, the results demonstrate that auditory priming facilitates the acquisition of word meaning (Merriman & Marazita, 1995), production and phonological generalization (Gierut & Morrisette, 2013 and herein). Convergence of evidence across lexical and phonological domains lends support to Church and Fisher's hypothesis (1998) that long-term exposure to auditory input through priming affords the experiences necessary to the formation of internal representations of words.

While Church and Fisher (1998) intended priming as an explanatory account of how phonology and the lexicon emerge, additional demonstrations are certainly needed. Nonetheless, the symmetry of the data fits with the view that phonology and the lexicon are engaged in a bidirectional relationship in acquisition (Stoel-Gammon, 2011). The structure of the sound system influences lexical learning and the structure of words influences phonological learning. This underscores the necessity of an integrated research approach that takes into account the interface of phonology and the lexicon (Ferguson & Farwell, 1975).

In this regard, it will be important to examine statistical regularities in auditory priming for both phonological and lexical learning. Thus far, available work has focused only on priming words from dense neighborhoods. While empirically motivated (Stoel-Gammon, 2011; Swingley & Aslin, 2002), other input regularities have been cited as also relevant to phonological and lexical learning. For example, it might be appropriate to consider priming words based on phonotactic probability because studies have shown that common sounds and sequences facilitate phonological (Edwards, Beckman, & Munson, 2004; Zamuner et al., 2004) and lexical acquisition (Storkel, 2001, 2003). Similarly, priming based on frequency of word occurrence and age-of-word-acquisition are other options. These too have been implicated in phonological (Gierut & Morrisette, 2011; Morrisette & Gierut, 2002) and lexical learning (Garlock, Walley, & Metsala, 2001). Research along these lines has the potential to reveal precedence relationships among regularities of the input. Under

conditions of auditory priming, some regularities may emerge as more important than others. Also, different regularities may affect different structural change in children's representations. When phonological regularities (e.g. phonotactic probability) are primed, the representation of sound structure may improve to a greater degree than referential knowledge of words. Conversely, when lexical regularities (e.g. word frequency) are primed, referential knowledge of words may improve more than phonological structure. Through work of this sort, it may be possible to identify the unique ways that input regularities dually and/or differentially aid phonological and lexical learning.

Methodological Implications

The present results stressed the importance of an auditory mode in prime delivery. Recall that, in prior literature, children had been exposed to both words and pictures in priming. This may have been done for ecological and/or practical purposes, but it also introduced ambiguity in the role of auditory and visual input on learning. The present findings established that pictures had less impact on phonological generalization than the spoken word (Greenhoot & Semb, 2008). The use of pictures in priming seems to be only a methodological nuance that does not challenge Church and Fisher's (1998) proposal.

There are, however, other aspects of the priming method that warrant clinical study. One is the effect of stories on phonological generalization. As priming has been implemented, children hear stories with prime words embedded; again, this may be for practical reasons. In future research, it will be necessary to test the effects of priming using citation lists. Predictably, a list format might boost phonological learning because a child would be exposed to minimal pairs without intervening or extraneous content. Yet, it is equally possible that a list format might be detrimental to phonological learning because the contextual support for meaning would be eliminated. Without meaning, the mapping of phonemic distinctions among words might be more challenging.

A second methodological question relates to the definition of 'long-term' priming. In this study, priming was provided at the start of each treatment session and continued for a maximum of 19 sessions. It is not known whether the benefits to phonological generalization might be realized in a shorter duration or if longer durations of priming might further enhance the learning effects.

Clinical Implications

The present study of PD complements priming in treatment of other language disorders, including aphasia (Blumstein, Milberg, Brown, Hutchinson, Kurowski, & Burton, 2000) and Specific Language Impairment (Leonard et al., 2000). Additional research is needed though to broaden the scope of applicability in clinical treatment, generally and PD, specifically. The latter would address limitations of the present study, including the small sample size, treatment of errors due only to exclusions from the phonemic inventory and treatment of only a narrow range of target sounds. Extensions that involve more participants with treatment of a wider range of error patterns and target sounds would allow for replications in establishing the robustness of priming for phonological generalization.

It will also be important to continue to refine and evaluate priming for clinical treatment. To date, rhyme priming has been implemented, but studies of onset priming are also needed. Onset priming would expose a child to primes and treated words that share the same onset, e.g. ‘lip, lamb, leaf’ prime the treated word ‘leap’. This manipulation is relevant in view of onset/rhyme asymmetries that have been noted in the literature. For example, in perceptual development, rhymes facilitate word naming in 5-year-olds, but onsets are only facilitating at ages 7 and older (Brooks & MacWhinney, 2000). In production, rhymes are more accurate than onsets in early phonological development and a wider range of phonemic contrasts is used in rhyme position (Dinnsen & Farris-Trimble, 2008). Computational studies have established rhymes as more reliable cues than onsets in English (Kessler & Treiman, 1997), a finding that is also realized in the structure of a child’s lexicon (Gierut, Morrisette, & Brown, in press). Work on adults has further shown that rhymes facilitate response time across a variety of psycholinguistic tasks (e.g. lexical decision making, picture naming, picture-word interference, shadowing), whereas onsets have inhibitory effects (Damian & Duamy, 2007; Radeau, Morais, & Seguí, 1995). Based on this literature, it is possible that onset and rhyme priming may lead to differential phonological generalization. Onset priming may not be as successful, but this must be established empirically to inform phonological treatment efficacy.

This notwithstanding, the present results provide an opportunity to sketch a preliminary recommendation for the application of priming to clinical treatment of PD. Namely, priming is efficacious to phonological generalization when delivered in the auditory modality (with or without pictures) using words from dense neighborhoods that overlap in rhyme structure with the words to be treated. Elaboration of this recommendation through continued research that cross-cuts theory, methodology and application is likely to lead to a better understanding of how the input contributes to phonological learning within the larger scheme of the study of language acquisition.

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APPENDIX

Stimuli for /l/

Treated stimuli	Auditory input	Visual input
leap	All the <u>sheep</u> fell in a big <u>heap</u> . They began to <u>peep</u> and <u>weep</u> . Farmer said, <u>keep</u> quiet <u>sheep</u> , don't make a <u>peep</u> . I have this <u>deep</u> field to <u>reap</u> and time is not <u>cheap</u> .	
lake	Watch Mrs. <u>Sake</u> <u>bake</u> . You'll laugh so hard, your side will <u>ache</u> ! To <u>make</u> a cake she uses a <u>rake</u> . Before it's done, she'll <u>take</u> it and <u>shake</u> . Then her <u>cake</u> is ready to <u>bake</u> .	
let	The man was <u>set</u> to take his <u>pet</u> to the <u>vet</u> . What did he <u>get</u> ? asked the <u>vet</u> when they <u>met</u> . He got very <u>wet</u> , and he hasn't dried <u>yet</u> . He'll <u>get</u> better, I <u>bet</u> ."	
lick	<u>Wick</u> the <u>tick</u> told his little friend <u>Rick</u> , let's ride on the <u>chick</u> 'cuz the grass is too <u>thick</u> . It would make a <u>tick</u> sick to <u>kick</u> and <u>pick</u> through grass that <u>thick</u> !	
lead	By the <u>red shed</u> , there's a log that's dead, where the mouse is <u>fed</u> and lays his <u>head</u> in a <u>bed</u> . Today I'll be <u>wed</u> in the <u>red shed</u> ! he <u>said</u> .	

Treated stimuli	Auditory input	Visual input
late	<p><u>F</u>ate sat by the <u>g</u>ate to <u>w</u>ait for her <u>d</u>ate. I <u>h</u>ate to <u>w</u>ait after I just <u>a</u>te! Along came her <u>d</u>ate at a very fast <u>r</u>ate. I thought we'd go fishing, but I lost my <u>b</u>ait.</p>	

Note: Primes are underlined in the respective stories.

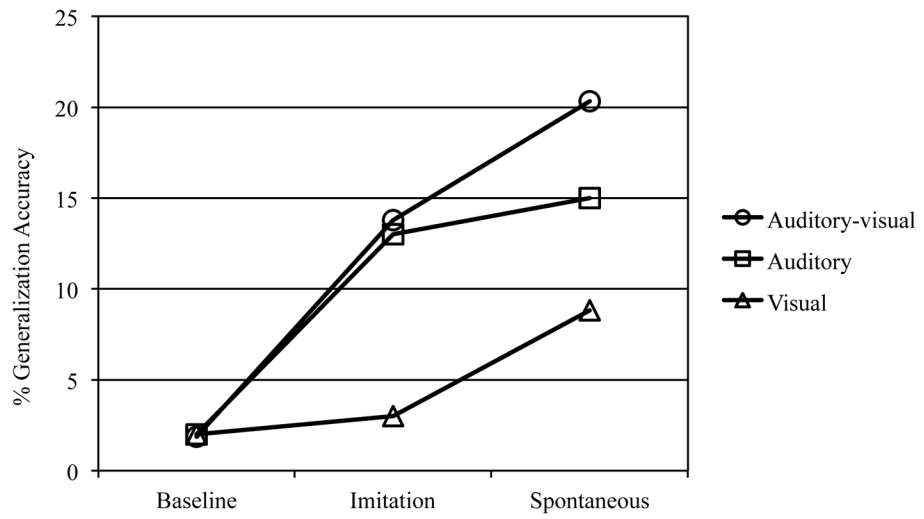


Figure 1. Generalization associated with auditory-visual, auditory and visual priming.

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Table 1

Participant characteristics

Condition	N	Age ^d	GFTA-2 ^b	N sounds excluded	PPVT-3 ^c	EVT ^d	Attention ^e	Working memory ^f
Auditory-visual	3	4:0 (3;5-4;7)	58 (54-64)	11 (10-13)	102 (93-110)	106 (101-110)	9 (6-10)	37 (30-44)
Auditory	3	4;6 (3;8-5;7)	63 (46-75)	9 (7-10)	124 (119-130)	113 (98-126)	10 (10-10)	34 (31-40)
Visual	3	4;10 (4;1-5;6)	65 (40-83)	9 (7-14)	116 (106-131)	112 (98-124)	9 (7-10)	34 (32-36)

Note: Mean values (and range) are reported for each condition.

^a Age values are reported in years;months.

^b Standard scores on the *Goldman-Fristoe Test of Articulation-2* (Goldman & Fristoe, 2000).

^c Standard scores on the *Peabody Picture Vocabulary Test, Third Edition* (Dunn & Dunn, 1997).

^d Standard scores on the *Expressive Vocabulary Test* (Williams, 1997).

^e Scaled scores on the Attention subscale of the *Cognitive/Social Rating of the Leiter International Performance Scale-Revised* (Roid & Miller, 1997) are interpreted relative to an average score of 10, with clinical significance noted for scores 6 and below.

^f Scaled scores on the Auditory Sequential Memory subtest of the *Illinois Test of Psycholinguistic Abilities-Revised* (Kirk, McCarthy, & Kirk, 1968) are interpreted relative to a $M=36$ ($SD=6$).

Table 2

Characteristics of stimuli

Characteristics	Treated stimuli	Prime stimuli
Age-of-word-acquisition ^a	3.10	2.99
Log frequency	2.77	2.53
Sum of segment frequency ^b	0.81	0.45
Sum of biphone frequency ^b	0.40	0.28

Note:

^a Age-of-word-acquisition ratings on a 7-point scale (Bird, Franklin, & Howard, 2001; Gilhooly & Logie, 1980).

^b Sum of segment frequency and sum of biphone frequency values represent *z*-score transformations for word length (Storkel, 2004).

Table 3

Learning during treatment

	Session-by-session ^a			McNemar ^b		<i>p</i>
	N sessions	% Imitation	% Spontaneous	Baseline	Spontaneous	
Auditory-visual	15 (6–19)	72 (50–85)	84 (73–98)	0/18	18/18	<.001
Auditory	11 (6–18)	85 (78–89)	94 (83–100)	0/18	13/18	<.001
Visual	13 (5–17)	84 (77–95)	97 (94–100)	0/18	13/18	<.001

Note:

^aMean values (and range) are reported for each condition.

^bProduction of the trained sound in the trained context of trained words at baseline and at completion of spontaneous training.

Table 4

Summary of generalization

Condition	10% cut-off ^a			McNemar ^b		Effect size <i>d</i>		
	Baseline	Spontaneous	Gain	Criterion met?	Baseline		Spontaneous	
Auditory-visual	2	20	18	yes	0/63	8/63	.008	7.92
Auditory	2	15	13	yes	0/63	12/63	<.001	7.04
Visual	2	9	7	no	1/63	5/63	.219	2.77

Note:

^a Mean percentages reported for each condition.

^b Production of the trained sound in untrained words and contexts at baseline and completion of spontaneous training.