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Lexical constraints in phonological acquisition*

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ABSTRACT

Lexical diffusion, as characterized by interword variation in production, was examined in phonological acquisition. The lexical variables of word frequency and neighbourhood density were hypothesized to facilitate sound change to varying degrees. Twelve children with functional phonological delays, aged 3;0 to 7;4, participated in an alternating treatments experiment to promote sound change. Independent variables were crossed to yield all logically possible combinations of high/low frequency and high/low density in treatment; the dependent measure was generalization accuracy in production. Results indicated word frequency was most facilitative in sound change, whereas, dense neighbourhood structure was least facilitative. The salience of frequency and avoidance of high density are discussed relative to the type of phonological change being induced in children's grammars, either phonetic or phonemic, and to the nature of children's representations. Results are further interpreted with reference to interactive models of language processing and optimality theoretic accounts of linguistic structure.

INTRODUCTION

The challenge for a theory of phonological acquisition is to provide a systematic account of variation that is observed within and across children's productive grammars. Despite a continued search for universal patterns and tendencies following from Jakobson (1941/1968), it is well established that different children acquire different sounds at different rates and in different

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orders. For a given child, an acquired sound may be used correctly in some target words or word positions, but not others. Moreover, the very same words may even be produced in multiply different ways. While some cases of phonological variability can be directly traced to the effects of phonetic context, a majority of other cases seem to be less systematic, predictable, or regular. For the most part, unpredictable variability in phonological acquisition has attracted functional explanations, being attributed to children's unique cognitive styles, learning strategies, preferences for (or avoidances of) certain sounds, word shapes, or articulatory routines (e.g. Interactionist-Discovery Model, Macken & Ferguson, 1983). These factors have all been thought to influence the acquisition process, thereby resulting in the individual differences that are observed.

The goal of this paper is to adopt an alternate structural perspective in examination of seemingly unpredictable variability in phonological acquisition. In particular, we will draw from and integrate psycholinguistic and linguistic frameworks to demonstrate that the lexical properties of words differentially influence children's productions in much the same way that these very same variables have been shown to affect spoken word perception. We then offer a viable account of the lexical effects by appealing to formal linguistic and psycholinguistic models. By extending linguistic constructs to the psycholinguistic domain and *vice versa*, it will thus be possible to suggest an interface between the phonology and the lexicon in acquisition.

Variation in phonological acquisition

Four main types of variation have been described in phonological acquisition: inter- and intrachild differences, and inter- and intraword differences (Ingram, 1979). INTERCHILD VARIATION refers to the ways in which different children master the productive phonology; whereas, INTRACHILD VARIATION is the way in which a particular child varies his or her productions. Subsumed under the latter are intra- and interword variability. INTRAWORD VARIATION is when a child produces a given word in different ways, and INTERWORD VARIATION is when a child produces a target segment in different ways across words and contexts.

In this paper, we focus exclusively on interword variability that is not predictable by context because it presents an unusual paradox. Consider that when a child acquires a new sound, it is typically used in certain words but not others. There is inconsistency in production, with some words being produced accurately and others, inaccurately. Gradually, the newly acquired sound comes to be used more and more appropriately across words. The real question is why newly acquired sounds are not used in all relevant lexical items from the outset. The fact is that, phonologically, the child has shown that prior phonotactic restrictions on the kinds of phonemic distinctions and segments permitted in the grammar have been lifted. Motorically, the child has also demonstrated an articulatory ability to produce the sound. If a child has both the phonological and the motoric capabilities, then why does interword variation result? To best address this, it is necessary to consider two additional questions: what are the properties of the words that are vulnerable to production accuracy? And, what is the course of productive sound change over time?

Evidence from spoken word perception. Potential insight into the first question regarding lexical vulnerability in production comes from research on spoken word perception in adults and children. It has long been noted that the properties of word frequency and neighbourhood density are relevant to the perceptual recognition of words by adults. WORD FREQUENCY refers to the number of times a given word occurs in a language; whereas, NEIGHBOURHOOD DENSITY is defined as the number of words that minimally differ in phonetic structure from a target word as based on one phoneme substitutions, deletions, or additions (e.g. 'pick,' 'it,' 'spit' are all neighbours of 'pit'). Neighbourhood density essentially identifies a word's minimal pair counterparts. Numerous studies have demonstrated that adults recognize high frequency words faster and more accurately than low frequency words (e.g. Landauer & Streeter, 1973). Similar facilitating effects in spoken word recognition have also been observed for words from low density neighbourhoods (e.g. Luce, Pisoni & Goldinger, 1990). Thus, a word's frequency and its density have been said to enhance a listener's access to lexical structure, and his or her ability to perceive and recognize spoken words.

These observations have recently been extended to perceptual development to determine if the properties of word frequency and neighbourhood density also contribute to the formation of lexical structure (Jusczyk, 1997 and references therein). Experimental evidence supports that normally developing infants and children are attuned to high frequency words in early lexical learning. Moreover, they perceptually attend to, and accumulate phonetically similar forms, biasing the development of high density neighbourhoods. Notice that the findings from fully-developed and normally developing systems seem to differ: high frequency, LOW density words are facilitating in adult perception, but high frequency, HIGH density words appear to be important in children's perception. These differences not withstanding, it seems that, at least in the perceptual domain, the organization of the developing mental lexicon may well depend on a word's frequency and its density. If word frequency and neighbourhood density are critical to the formation of lexical structure as these preliminary data suggest, then a necessary consideration is whether these same factors are also operative during longitudinal change in that structure, as in the case of productive sound change.

Evidence from lexical diffusion. The study of historical linguistics is especially revealing of the issue of sound change given its detailed documentation of diachronic change in the productive phonologies of languages of the world. Two distinct types of historical sound change have been identified: mergers wand splits (Labov, 1994 and references therein). Splits are most relevant to concerns of phonological development because a single phonemic distinction is being divided into multiple categories. In other words, the number of distinctive contrasts in a language is elaborated when a split is introduced. This parallels the case of acquisition where the number of segments in a child's phonological repertoire is expanded over time. There are also two distinct ways in which historical sound change takes place: across-the-board change versus lexical diffusion. Lexical diffusion is the more applicable to phonological development because this process is characterized by a gradual implementation of productive change that is infused into the grammar on a word-by-word basis. This essentially mirrors the case of interword variation. In fact, it has been argued that the study of phonological acquisition is an accelerated version of historical sound change in progress. Lexical diffusion is also most prevalent in phonological development, with those few reports of across-the-board change having been challenged in the literature (cf. Smith, 1973, but also Macken, 1980; Dinnsen, 1996).

For fully-developed systems, splits by lexical diffusion have been associated, in part, with a word's frequency. It had long been maintained that high frequency words were most vulnerable to productive change because they were important to distinctness in communication, as compared to other words that were rarely used. More recent investigations, however, have revealed differential effects of word frequency on productive sound change (Phillips, 1984). Specifically, high frequency words have been shown to change first in a grammar if subtle phonetic distinctions are introduced. In comparison, low frequency words change first if new phonemic contrasts are being interjected. Stated another way, surface-level (or allophonic) distinctions are realized in high frequency words, whereas underlying lexical distinctions are manifested in low frequency words.

For developing systems, there have been only two studies that have considered the effects of word frequency on productive sound change, yielding mixed results. Furthermore, both were cross-sectional investigations, thereby precluding any examinations of the course of productive sound change in acquisition. Leonard & Ritterman (1971) observed that children's production accuracy improved to a greater degree in high as opposed to low frequency words. In a replication and extension of this, Moore and colleagues (1976) found no effects of word frequency on children's production accuracy. From the limited developmental data, the role of word frequency in productive sound change remains unclear.

An experimental test

The view of interword variation in acquisition that we have sketched thus far merges the psycholinguistic properties of word frequency and neighbourhood density with the linguistic attributes of lexical diffusion. The available findings present a potentially insightful, but incomplete and often conflicting view of the role of word frequency and neighbourhood density in spoken word perception as compared to production, and in fully-developed as compared to developing systems. These gaps and discrepancies served to further motivate the present study where we explored the possibility that children's interword variability may be directly traceable to the frequency and density characteristics of words.

To test this possibility, lexical diffusion in children's productive sound systems was experimentally induced by systematically manipulating frequency and density. This required a special population because children had to have an established and extensive expressive and receptive vocabulary, but they also had to still be merging phonological distinctions so as to produce errored outputs. A prime population that fits this description is children with functional phonological delays. With exception of their productive sound system, these children are normal in all other linguistic and non-linguistic aspects of development. Their sound system, however, is extremely impoverished, consisting of a severely reduced consonantal repertoire. Because the children are highly unintelligible due to the prolonged static nature of their phonology, they warrant direct training and instruction to induce change in the sound system. This training is structured as an experimental treatment manipulation, with dependent measures of phonological generalization being obtained over time as a direct reflection of the acquisition course. Since the children are older, they can complete complex linguistic tasks that are central to the treatment and to the establishment of phonemic (as opposed to phonetic) distinctions. Of most importance, the results which obtain from this population have been widely demonstrated to parallel the patterns of normal phonological development and the structure of fully-developed sound systems (e.g. Ingram, 1989; Bernhardt, Gilbert & Ingram, 1996). The points of similarity that unify the populations extend to all aspects of phonological structure, including the composition of phonetic and phonemic inventories, distributional properties and asymmetries, allophonic and neutralizing phonological rules, and phonotactics. Because the phonological properties evidenced in functional delays strongly resemble those of fully-developed and normally developing systems, there is the potential for broad generalizability of the findings across populations.

In the present study, children with functional phonological delays participated in treatment designed to induce change in their productive sound systems. They were taught target sounds, which were phonotactically restricted from their grammars, in words that were of high/low frequency and/or high/low density. Generalization probe measures were administered longitudinally to determine the extent of productive sound change that took place under the different treatment conditions. The general hypothesis was that frequency and density will enhance productive sound change to varying degrees in development. Other more specific predictions also emerge depending on the type of evidence being considered. For example, following from the developmental perceptual data, one prediction is that high frequency words and high density neighbourhoods will facilitate children's productive sound change. When the results from adult spoken word perception are considered instead, an alternate hypothesis is that high frequency words and low density neighbourhoods will motivate sound change in development. A third possibility derives from the findings of historical sound change; that is, low frequency words will trigger changes in children's productive phonologies, with the effects of neighbourhood density as yet undetermined. The resulting outcome was a relative ranking of the lexical variables that promoted the greatest productive phonological change. These findings are discussed relative to psycholinguistic and linguistic perspectives on interword variation in development.

METHODS

Participants and their phonologies

Twelve children with functional phonological delays, aged 3;0 to 7;4, served as subjects. Children were recruited through public announcement to local schools,reschools and programmes, and were identified as potential subjects following comprehensive evaluations of their speech, language, and hearing abilities. Conventional entry criteria, consistent with prior literature (Gierut, Morrisette, Hughes & Rowland, 1996), required that all children exhibit normal hearing, oral-motor structure and function, and non-verbal intelligence. On linguistic grounds, all children were required to demonstrate age-appropriate vocabulary, and expressive and receptive language abilities as determined by performance on standardized measures. They also resided in monolingual English-speaking homes.

To participate, children were required to exhibit broad-based errors in production of target consonants, as determined by converging relational and independent analyses (Stoel-Gammon & Dunn, 1985). From a relational perspective, they were to perform at or below the 3rd percentile on the *Goldman-Fristoe test of articulation sounds-in-words subtest* relative to age- and gender-matched peers. From an independent perspective, they were to exclude a minimum of seven target English consonants from their phonemic repertoires. To establish this, detailed speech samples were first elicited,

TABLE 1. *Subjects and experimental assignments*

Experimental conditions	Subject	CA	Gender	Phonemes excluded	Treated Sounds
HI frequency vs. LO	1	4;0	M	v θ ð s z š č ǰ l r	s vs. š
frequency	2	4;8	M	ŋ k g f v θ ð s z š č ǰ l r	g vs. l
HI density vs. LO	3	4;8	F	ŋ f v θ s z r j	f vs. θ
density	4	3;6	F	k g θ ð š ǰ l	l vs. š
HI frequency vs. HI	5	5;2	M	v θ ð š č ǰ r j	v vs. š
density	6	7;4	M	ŋ k g v θ ð s z š l r	v vs. š
LO frequency vs. LO	7	4;5	M	ŋ k g f v θ z r	g vs. r
density	8	4;8	M	f v θ ð s z š l r	θ vs. š
HI frequency vs. LO	9	4;7	M	θ ð z š č ǰ l r	r vs. θ
density	10	3;0	F	ŋ k g f θ ð s z š č ǰ r j	θ vs. s
LO frequency vs. HI	11	4;4	M	ŋ k g θ ð s z š č ǰ l w h	s vs. g
density	12	3;1	M	f v θ ð s z š č ǰ l r	f vs. s

audiorecorded, and phonetically transcribed for each child. The sampling procedures ensured ample opportunity to produce each target consonant, onset and coda cluster in each relevant context in at least five different exemplars (Gierut, Elbert & Dinnsen, 1987). Then, a child's phonemic repertoire was determined based on the occurrence of unique sets of minimal pairs, following previously established criteria (Gierut, Simmerman & Neumann, 1994). Target sounds that were used contrastively were taken to be phonemic; all others were excluded from a child's repertoire.

Table 1 lists the target consonants that were phonotactically restricted from each child's inventory following from these criteria. Across children, the mean number of target sounds that were never produced or used was 10 (range = 7 to 14 phonemes). All children excluded some fricatives and at least one liquid from their inventories, and half of the children also excluded velar stops and/or affricates. At first glance, it may be thought that the number and type of phonemes excluded from children's repertoires may be associated with chronological age; however, this was not the case. To illustrate, Subject 12 was among the very youngest to participate at age 3;1; whereas, Subject 6 was the very oldest at age 7;4. Despite age differences, both children excluded exactly the same number of phonemes ($n = 11$) from their inventories. As a complementary illustration, Subjects 4 and 10 were both in the three-year age range. Yet, Subject 4 excluded the fewest number of sounds of all children who participated ($n = 7$), whereas Subject 10 excluded nearly the maximum number of sounds ($n = 13$). Here, despite a commonalty of age, the number of sounds these children excluded were at the extremes. In a similar way, the type of segments excluded from children's repertoires also could not be attributed to developmental considerations. For example, velar stops are among the earlier acquired sounds by normative report. In this study, neither the youngest nor the oldest children (Subjects 10 and 6, respectively) had acquired these segments. From a reverse perspective, /θ ð/ are taken to be late acquired fricatives, but again, neither the youngest nor the oldest child had internalized these as phonemes. These observations about the independence of inventory structure relative to chronological age are wholly consistent with previous literature (Gierut *et al.*, 1994; Dinnsen, 1998).

Together, the relational and independent data established that a child's consonantal repertoire was severely impoverished, thereby contributing to extreme unintelligibility, and that phonological treatment was warranted to induce positive changes in production. Further, those sounds that were excluded from a child's phonemic inventory formed the pool of potential targets to be considered for treatment.

Experimental design

A complex single-subject experimental design combining alternating treatments with multiple baselines was used (McReynolds & Kearns, 1983). By way of overview, single-subject designs do not assume homogeneity of the population for purposes of statistical comparisons; rather, each subject serves as his or her own experimental control. This is a significant consideration in the study of phonological acquisition (normal or delayed) given observed individual differences. Generality of experimental results is achieved instead through direct or systematic replication. Direct replication is accomplished when different children exhibiting similar patterns perform in the same way by experimental condition. Systematic replication occurs when different children exhibiting different patterns respond in the same way by experimental condition. Systematic replication is the more powerful because it demonstrates that the experimental manipulations hold regardless of the entry-level characteristics or performance of the children.

Regarding the specific designs used herein, the alternating treatments exposes a given subject to two different experimental conditions concurrently, with the conditions being rapidly and randomly varied. The premise is that the subject will distinguish between conditions and will behave differentially and preferentially, such that performance in one condition will exceed that of the other. In complement, a multiple baseline design exposes a subject to a period of no-treatment followed by treatment, with the number of pretreatment baselines increasing by one as subsequent subjects are enrolled. The underlying assumption is that baseline performance within and across children will remain stable and unchanged until the instatement of treatment; thus, any improvements in performance will be directly attributable to the treatment itself. As applied in this experiment, the alternating treatments were implemented by exposing different children to different treatment conditions affiliated with word frequency and/or neighbourhood density as the independent variables. The multiple baseline was overlaid on the alternating treatments, such that two children were assigned to each experimental manipulation, thereby providing a systematic replication of the behavioural effects.

Independent variables

The logically possible combinations of high/low word frequency were crossed with high/low neighbourhood density to form the full set of experimental conditions. Pairs of children were randomly assigned to these conditions, as in Table 1. For each child, two sounds excluded from the phonemic repertoire were selected for treatment. Further, each sound was independently affiliated with a particular lexical property. To illustrate, Subject 1 was randomly assigned to the experimental manipulation comparing performance following treatment of high frequency words to that of low frequency words. In the high frequency condition, this child was taught /s/, and in the low frequency condition, /š/. His paired replication was Subject 2, who was taught /g/ in high frequency words and /l/ in low frequency words.

The particular sounds that were assigned to each lexical condition were selected somewhat arbitrarily, with the following restrictions in mind. Treated sounds were always more marked relative to the pretreatment contrasts of a child's system. This guaranteed that structurally more complex sounds and contrasts would be introduced, thereby potentially facilitating generalization and elaboration of the phonological system. This is consistent with, and derives from prior experimental demonstrations that treatment of seemingly more difficult, more marked, or superordinate properties of phonological structure trigger the greatest learning and change (Gierut *et al.*, 1996 for review). Sounds that were treated were also motorically stimulable; that is, a child was able to accurately articulate the treated sound following the experimenter's verbal model. This demonstrated that a child had the capacity to approximate the motor gestures involved in accurate sound production, even though the sound to be treated was consistently produced in error and excluded from the phonemic repertoire. Treated sounds always involved simple onsets; consequently, affricates and clusters were avoided as potential targets. Treated sounds were always presented in the word-initial position during treatment to enhance their salience. Finally, across children, each treated sound was replicated in the alternate word frequency or neighbourhood density condition. To illustrate, /s/ was taught in a frequency manipulation for Subject 1 as noted, but /s/ was also assigned to the alternate density condition in the case of Subject 10. This was intended to ensure that the effects of treatment could not be solely attributed to the specific segments being taught.

Each treated sound was taught in eight stimulus words that conformed to the lexical property being manipulated. Word frequency was determined with reference to the counts of Kučera & Francis (1967), and neighbourhood density, with reference to a computational on-line version of the Merriam-Webster (1964) Pocket Dictionary which contains 20,000 computer readable phonemic transcriptions (Nusbaum, Pisoni & Davis, 1984). These sources are conventional to the methodologies of other published investigations of lexical properties in developing and fully-developed systems, and were used herein for comparison purposes. In this study, high frequency words had a mean count of 153 per million, and low frequency words, a mean count of 15 per million. High density neighbourhoods had a mean of 21 phonetically similar forms, whereas low density neighbourhoods had a mean of only three such forms. It must be recognized that the mean values of frequency and density are relative, and that their operational definitions have varied across studies. This notwithstanding, it has been demonstrated that speakers of a language will converge on similar relative values of word frequency and neighbourhood density, despite obvious differences in their linguistic experiences (Kelly & Martin, 1994). The reason lies in the robustness of statistical sampling: as the size of a sample increases, it actually reflects the population from which it was drawn. As applied linguistically, while no two speakers will have exactly the same language exposure, they will draw similar conclusions about the relative status of words in that language because of the sufficiently large size of the input sample.

In addition to frequency and density considerations, the stimulus words selected for treatment had to be both familiar and picturable to young children. Familiarity was discerned from the computational database, with the mean familiarity rating of the treated words being 6·89 on a 7·0 scale (with 7·0 being highly familiar). Stimulus words were presented as picturable, digital displays available through the Picture Gallery programme (Psychological Corporation, 1995) for uniformity in teaching.

In the selection of stimulus words for treatment, it was also important to recognize that any given word had both a frequency and a density value. Consequently, when a particular lexical property was being manipulated in treatment, the alternate untreated parameter was controlled to avoid any potential confounds. For instance, if high frequency was the property of words being manipulated, then these words had to be drawn equally from both high and low density neighbourhoods. Similarly, if high density was the experimental variable of interest, then the treated words were to be of both high and low frequency. To illustrate this more concretely, the treated words for Subject 1 are shown in Table 2. Recall that, for this child, /š/ was affiliated with the low frequency treatment condition. Accordingly, the /š/

TABLE 2. *Sample of treated words for Subject 1*

	Frequency		Density		
	High	Low	High	Low	Familiarity
Shuttle	—	1	—	5	6·83
Shepard	—	3	—	1	6·92
Shiny	—	3	—	3	7·00
Sugar	—	34	—	0	6·67
Shack	—	1	22	—	7·00
Shake	—	17	24	—	7·00
Shell	—	22	21	—	7·00
Sheep	—	23	20	—	7·00
Mean	—	13	22	2	6·93
City	393	—	—	7	7·00
Section	189	—	—	2	7·00
Secret	78	—	—	0	7·00
Safety	47	—	—	0	6·92
Serve	107	—	14	—	7·00
Sign	94	—	31	—	7·00
Sail	56	—	34	—	7·00
Seat	54	—	32	—	7·00
Mean	127	—	28	2	6·99

words that this child was taught had a mean frequency count of 13 per million. Half of these words came from low density neighbourhoods, with a mean density of two, and half from high density neighbourhoods, with a mean density of 22. The /š/ words were all familiar having a mean rating of 6·9 on the 7·0 scale, and were also available in the Picture Gallery set. A comparable circumstance obtained for the /s/ stimulus items which were treated in the high frequency condition for this child. The treated stimulus sets for all children followed this general pattern.

Procedures

Treatment sessions were each one hour in duration, with treatment administered three times weekly. Following Gierut *et al*. (1996), each session was divided into two blocks, with one lexical condition introduced in one block, and the alternate condition in the other block. Between blocks, there was a 10-minute non-speech-related rest to signal a shift in the experimental conditions. Across sessions, the order of presentation was randomly varied and counterbalanced, such that each experimental condition was introduced first in a session an equal number of times.

Treatment proceeded in two phases: imitation, followed by spontaneous production of treated sounds in the pictured stimulus words. During the imitation phase, a child was to name the stimulus picture following the experimenter's verbal model, with feedback provided as to the accuracy of the production. Imitation treatment continued until a child achieved 75% accuracy over two consecutive sessions or until seven total sessions were completed, whichever occurred first. Once the imitation criterion was met in either experimental condition, treatment advanced to the next spontaneous phase. Here, a child produced the treated sound in the pictured stimulus words without a verbal prompt. Treatment continued in this mode until 90% accuracy over three consecutive sessions was reached, or until 12 total sessions were completed, whichever occurred first. Once this criterion was met in either experimental condition, the treatment was completed.

The production accuracy data collected during treatment were used to establish when a child was to move through the treatment sequence. These data also served to demonstrate that a child was able to produce the treated sounds with some degree of accuracy. For children of this study, maximum performance during the imitation phase ranged from 8% to 100%, and during the spontaneous phase, from 21% to 100% across lexical conditions. In addition, a child's performance during treatment was of further value as a secondary and supplementary source of evidence to the dependent variable, as described below.

Dependent variable

The dependent variable was generalization of the treated sound to untreated words and contexts, and to its cognate (in the case of treated obstruents). Generalization was of central concern because of its ecological validity in directly reflecting changes in a child's grammar, i.e. how a child may have differentially internalized sounds under the different experimental lexical conditions. Generalization was sampled on independent probe measures that were affiliated with each lexical condition. A probe consisted of common pictures sampling the treated sound and cognate in initial, intervocalic, and final positions in monomorphemic forms. Probes were equally balanced in terms of high/low frequency and high/low density items so as not to predispose (or alternatively, preclude) a generalized response based on the lexical characteristics of the probe words. Probes were administered throughout treatment following a predetermined, randomized variable ratio schedule of two sessions. That is, on average, a probe was given to a child every other session. Because this variable schedule was determined *a priori*, it was possible for the total number of probes to vary by experimental condition depending on how long a child remained in any given phase of treatment. Probe responses were spontaneously elicited through picture naming, were audiorecorded and phonetically transcribed. A subset of the probe data (14%) were retranscribed by an independent listener for purposes of establishing reliability. Mean point-to-point consonant transcription reliability was 91% agreement between listeners.

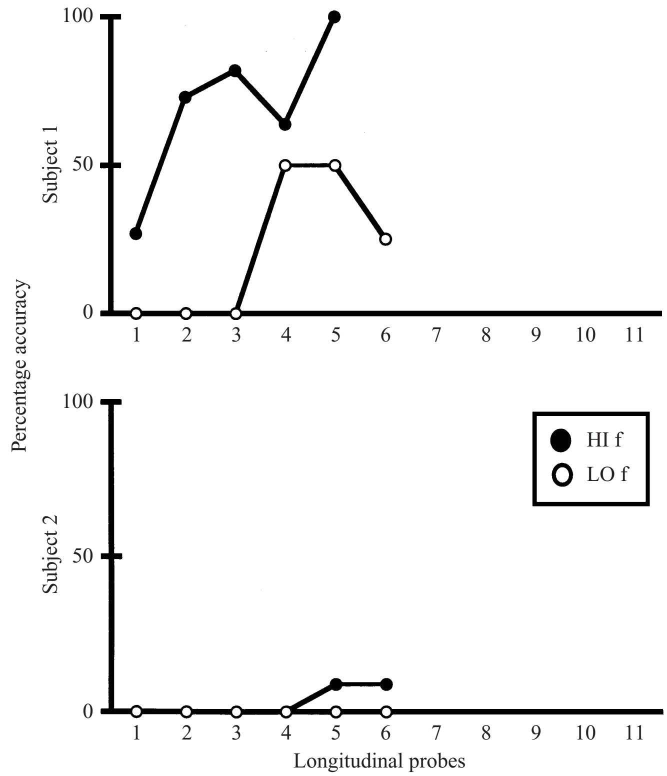

Fig. 1. Generalization curves for high vs. low frequency.

Following from the transcription data, the percentage probe accuracy was computed and plotted longitudinally as a generalization curve for each experimental condition for each child. The resulting generalization curves were evaluated descriptively with regard to the degree of phonological change that was observed under each of the experimental conditions. While statistical comparisons are not typical or necessitated in single-subject designs, *t*-test comparisons were conducted, with the probability value set at 0·05. As will be shown, these statistical comparisons did not always reveal significant differences between the experimental conditions, although the graphic generalization curves may have suggested otherwise. In those cases where the generalization effects could not be disambiguated across lexical conditions on statistical grounds, a child's performance during treatment was examined as a supplementary and secondary dependent variable (McReynolds & Kearns, 1983 for discussion). It must be emphasized that performance during treatment reflects only a child's production of the treated words during each treatment session. Consequently, these data are not revealing of internal changes in a child's grammar *per se*. Nonetheless, it was possible to appeal to treatment data to determine if a child did indeed exhibit preferential responding under the different experimental conditions. Performance during treatment was thus used to bolster seemingly tentative (statistical) generalization results about the relative impact of the independent lexical variables on phonological change.

RESULTS

The results of phonological treatment are displayed as generalization learning curves in Figs 1–6. The curves are discussed relative to differential per-

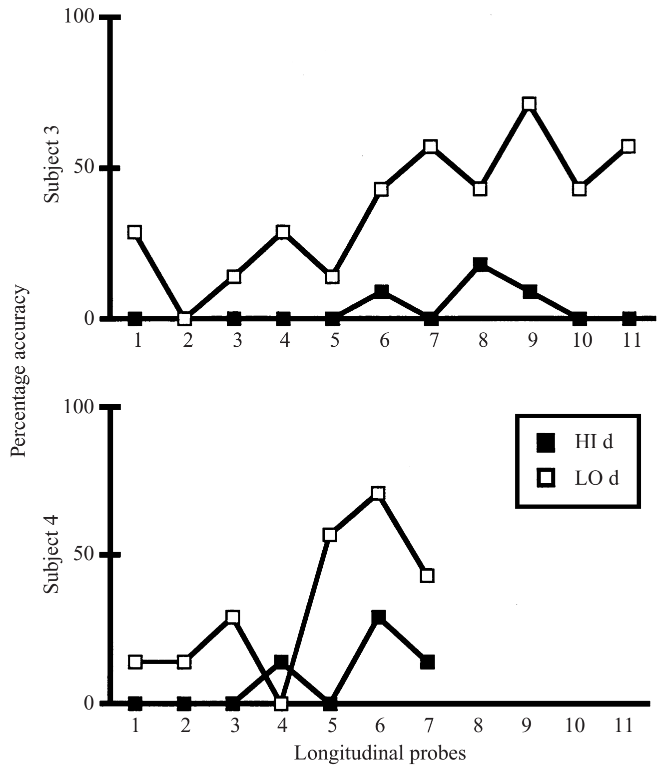

Fig. 2. Generalization curves for high vs. low density.

formance in the experimental conditions, with emphasis on that particular lexical variable which promoted the greatest generalization and change for a given child. Statistical analyses of the resulting learning data are reported as mean percentage accuracies in Table 3 for children's generalization performance, as well as their performance during treatment for each of the

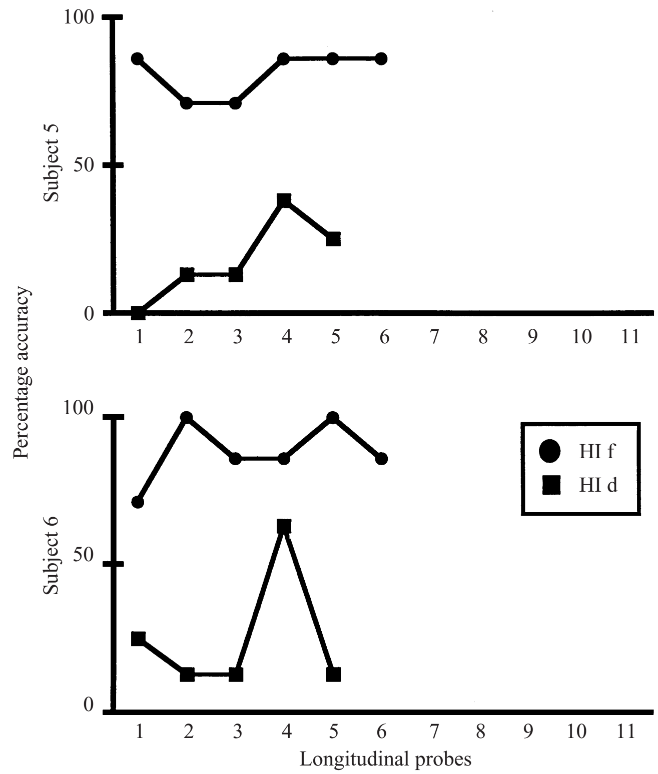

Fig. 3. Generalization curves for high frequency vs. high density.

experimental conditions. Mean probe performance was examined (rather than difference scores between the 0% baseline and the final generalization probe) so as to best capture children's variations in production over time.

Lexical property constant: vary degree

In a first set of manipulations, we held a single lexical variable constant, while varying its degree, as in the comparisons of high frequency to low frequency words, and high density to low density neighbourhoods. This allowed us to determine which dimension of a given lexical property may be most relevant in inducing productive sound change.

Figure 1 displays the generalization curves of Subjects 1 and 2, who each were exposed to high versus low frequency words in treatment. For Subject 1, treatment of high frequency words was more facilitative of generalization than treatment of low frequency words. This child achieved 100% accuracy in the high frequency condition at the final sampling, but only 25% accuracy in the alternate low frequency condition. Greater generalization thus incurred

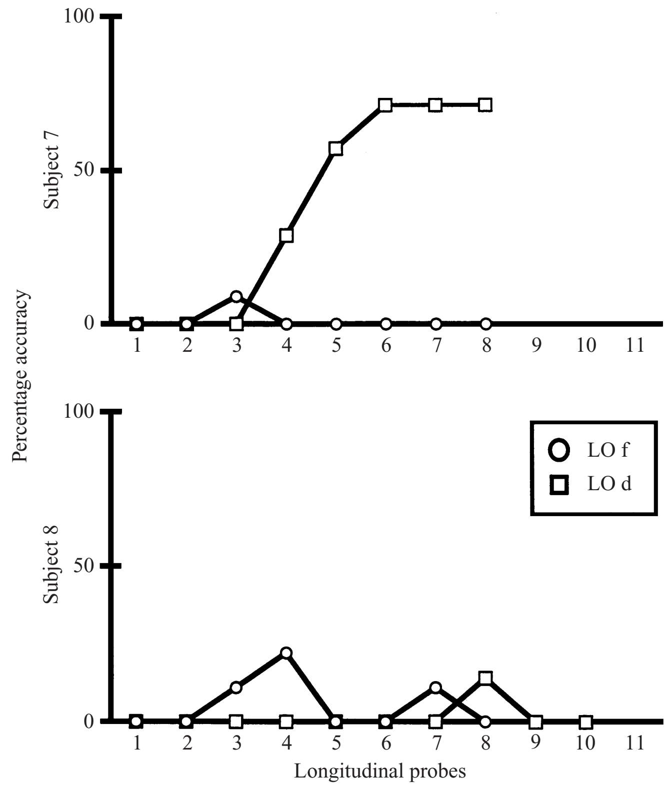

Fig. 4. Generalization curves for low frequency vs. low density.

following exposure to high, rather than low frequency words for Subject 1. Subject 2 exhibited a similar, but less dramatic demonstration of the positive effects of high frequency words on productive sound change. This child did not generalize treated sounds to untreated items until the final two sampling points. It was only then that the differential effects of the experimental conditions were observed, with Subject 2 seeming to favour the high frequency condition. Because so little generalization occurred, with mean differences between the treatments also being statistically non-significant (Table 3), it was necessary to consider the secondary data before advancing claims about the benefits of high frequency words for this child. We therefore turned to Subject 2's performance during treatment for insight to the preferential effects of the experimental conditions. The supplementary learning data reported in Table 3 confirmed Subject 2's generalization trend, and a preference for high frequency words. Mean performance during treatment of high frequency words was better than that of low frequency

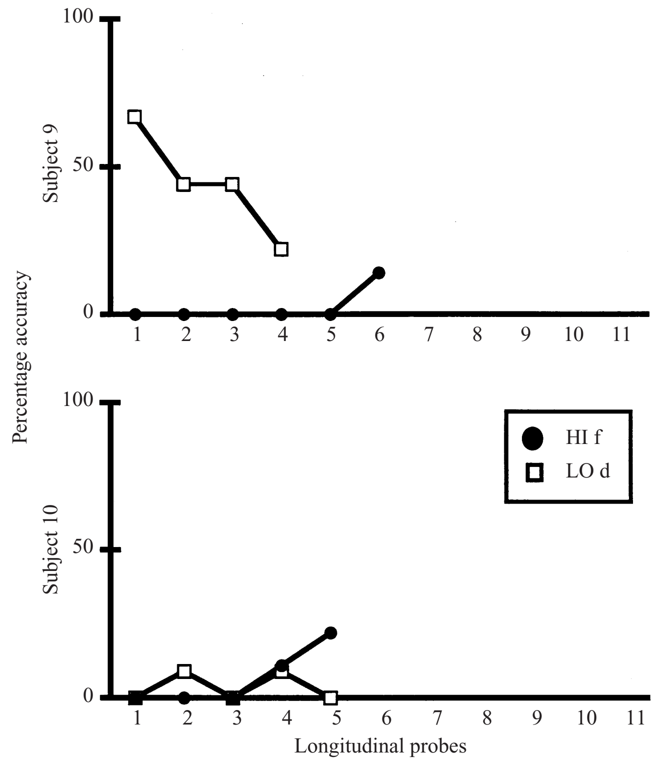

Fig. 5. Generalization curves for high frequency vs. low density.

words for this child. Thus, when primary and secondary sources of evidence were integrated in the case of Subject 2, the positive effects of high frequency words on productive sound change were supported. Overall, high frequency words were favoured by Subjects 1 and 2 of this experimental condition.

Figure 2 plots the generalization curves of Subjects 3 and 4 who were treated on words from high versus low density neighbourhoods. For both children, greater phonological gains were observed following exposure to words from low density neighbourhoods. Following treatment of low density words, Subject 3 generalized production with 57% accuracy at the final sampling point, as compared to 0% transfer of learning in the alternate high density condition. Likewise, Subject 4 exhibited 43% versus 14% accuracy on the final generalization probe affiliated with the low versus high density conditions, respectively. The evidence from both children thus converged on low density neighbourhoods as facilitating productive sound change.

In summary of this first set of manipulations, treatment of high frequency words and treatment of words from sparse neighbourhoods induced greater

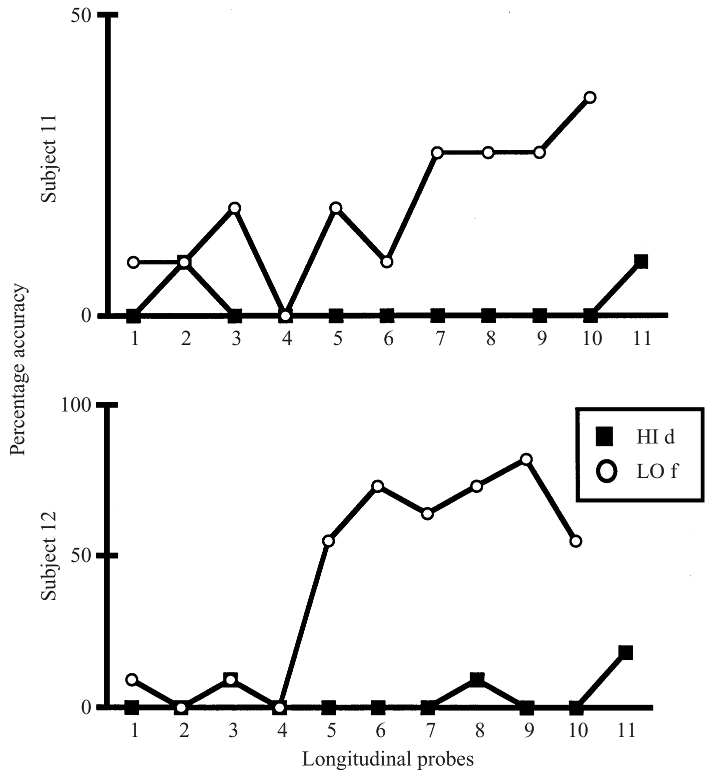

Fig. 6. Generalization curves for low frequency vs. high density.

change in children's productive systems. Stated conversely, low frequency words and high density neighbourhoods appeared to limit generalized sound change.

Degree constant: vary lexical property

In a second set of manipulations, we varied both lexical properties while holding their degrees constant. That is, treatment involved comparisons of high frequency versus high density items, and of low frequency versus low density items. This was intended as a potential replication of the prior effects in order to demonstrate the strength of each lexical property independent of its comparison condition.

The data in Fig. 3 show that Subjects 5 and 6 both exhibited greater generalization following treatment of high frequency words. High frequency words facilitated generalization to 86 % accuracy for both children at the final probe samples. The children's generalization was less than or equal to 25 % accurate performance in the comparison condition of high density neighbour-

TABLE 3. *Mean percentage accuracy in generalization and treatment*

Subject	Dependent variables	Experimental conditions: Frequency HI	Frequency LO	Density HI	Density LO	t-values and degrees of freedom
1	Generalization	69	21	—	—	$t = 3.11$, d.f. $= 9$*
	Treatment	84	55	—	—	$t = 3.03$, d.f. $= 16$*
2	Generalization	3	0	—	—	$t = 1.58$, d.f. $= 10$
	Treatment	61	28	—	—	$t = 2.84$, d.f. $= 18$*
3	Generalization	—	—	3	36	$t = 4.92$, d.f. $= 20$*
	Treatment	—	—	58	71	$t = 2.32$, d.f. $= 34$*
4	Generalization	—	—	8	33	$t = 2.31$, d.f. $= 12$*
	Treatment	—	—	27	66	$t = 3.90$, d.f. $= 22$*
5	Generalization	81	—	18	—	$t = 9.34$, d.f. $= 9$*
	Treatment	86	—	51	—	$t = 4.83$, d.f. $= 14$*
6	Generalization	88	—	25	—	$t = 6.26$, d.f. $= 9$*
	Treatment	91	—	67	—	$t = 2.11$, d.f. $= 14$
7	Generalization	—	1	—	37	$t = 3.01$, d.f. $= 14$*
	Treatment	—	3	—	65	$t = 7.29$, d.f. $= 24$*
8	Generalization	—	6	—	1	$t = 1.35$, d.f. $= 16$
	Treatment	—	75	—	23	$t = 5.77$, d.f. $= 16$*
9	Generalization	2	—	—	44	$t = 5.36$, d.f. $= 8$*
	Treatment	15	—	—	82	$t = 10.10$, d.f. $= 12$*
10	Generalization	7	—	—	4	$t = 0.61$, d.f. $= 8$
	Treatment	9	—	—	12	$t = 1.15$, d.f. $= 18$
11	Generalization	—	18	2	—	$t = 4.59$, d.f. $= 19$*
	Treatment	—	11	35	—	$t = 5.11$, d.f. $= 36$*
12	Generalization	—	42	3	—	$t = 3.79$, d.f. $= 19$*
	Treatment	—	2	21	—	$t = 4.29$, d.f. $= 36$*

* $p < 0.05$

hoods. These patterns lend additional support to the finding that high frequency words are positive motivators of productive sound change, and that high density neighbourhoods seem to be a disfavoured condition.

Figure 4 shows the comparison between low frequency and low density words for Subjects 7 and 8. The results of Subject 7 indicate that marked generalization followed treatment of words from low density neighbourhoods, with 71% accuracy of production at the final probe sample. In contrast, this child evidenced no generalization learning following treatment of low frequency words, with 0% accuracy in productions. Low density neighbourhoods thus emerged as the more facilitating condition for Subject 7, consistent with our previous observations. Subject 8, on the other hand, displayed only a modest transfer of learning following treatment. In both the low frequency and low density conditions, little sustained generalization took place, with production accuracies never exceeding 20% at any point in time. While the difference in mean probe performance across conditions was

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statistically non-significant, it appeared that Subject 8 may have favoured the low frequency condition given his intermittent generalized productions. When performance during treatment was also considered as secondary evidence (Table 3), the data indicate that Subject 8 did, in fact, perform better during treatment of low frequency words. Taken together, the data from Subjects 7 and 8 suggest that EITHER low density neighbourhoods or low frequency words promote productive change. Exposure to words with few phonetically similar counterparts or exposure to words of the language that are rarely used each enhanced generalization learning for these two children.

To sum the results of this second set of manipulations, we again found that high frequency words and low density neighbourhoods induced greater productive sound change. However, low frequency words were also shown to be relevant to change, but only in particular comparative conditions. Potentially, this implies that word frequency effects, albeit high or low, may outweigh the importance of neighbourhood density in inducing productive sound change in development.

Lexical property crossed with degree

A third set of manipulations fully-crossed the lexical parameters with their varying degrees. The specific treatment comparisons were high frequency versus low density words, and high density versus low frequency words. This set of comparisons was most critical because it had the potential to establish the relative contributions of what appeared to be the most facilitating and the least facilitating conditions of change. In this way, a best-of-the-best and a worst-of-the-worst lexical condition might emerge.

Figure 5 displays the results for Subjects 9 and 10, treated in the high frequency and low density conditions. Subject 9 demonstrated greater overall generalization in the low density as compared to the high frequency treatment condition, with statistically significant differences in mean probe performance. Inspection of the COURSE of generalization learning, however, offers a somewhat different interpretation. Notice that, at the outset of treatment, low density neighbourhoods clearly facilitated generalization with greater than 65% production accuracy on the probe measures. Yet, over time, these facilitating effects declined substantially. Importantly, when decrements were occurring in the low density condition, increments in generalization were beginning to be associated with the alternate high frequency condition. In fact, at the final probe samples, generalization learning in both conditions was nearly identical, with 22% and 14% accuracy in the low density and high frequency conditions, respectively. This generalization pattern suggests that the lexical variables may have cancelled each other, such that low density neighbourhoods and high frequency words had essentially equivalent effects on generalization learning. The data from Subject 10 are also consistent with a cancellation hypothesis, although the extent of generalization or learning during treatment was minimal for this child. While there were no statistically significant differences between the high frequency and low density treatment conditions for either the primary generalization data or for the secondary learning during treatment data (Table 3), the child's generalization curve merits discussion because it mirrors that of Subject 9, but on a much more modest scale. In particular, Subject 10 began favouring the low density treatment condition at early sampling points, but generalization performance declined to 0% accuracy in time. Treatment of high frequency words yielded no generalization at first, but eventually there was transfer of learning with 22% production accuracy at the final probe point. The generalization patterns of Subjects 9 and 10 thus support a conservative summary such that low density neighbourhoods may be as good as high frequency words in promoting productive sound change.

Figure 6 displays the comparison between treatment of high density neighbourhoods and low frequency words for Subjects 11 and 12. For both children, the low frequency condition resulted in greater generalization. Subject 11 produced generalization probe items with 36% accuracy at the final sampling following treatment of low frequency words. This was in contrast to 9% accuracy in the high density condition at the final sample. The generalization patterns of Subject 12 were more dramatic, with 55% versus 18% generalization accuracy in the low frequency versus high density conditions, respectively, at the final probe point. These findings replicated prior effects which demonstrated that exposure to words from high density neighbourhoods was least effective in inducing generalization. A worst-of-the-worst lexical property thus emerged from this comparison.

To summarize this third set of manipulations, both high frequency words and low density neighbourhoods had comparable impacts on productive sound change. When these seemingly most relevant variables to change were introduced in tandem, their facilitative effects appeared to cancel. In contrast, when the seemingly least relevant variables to change were compared, low frequency words promoted greater sound change than did high density neighbourhoods. This lends additional support to the observation that word frequency (high or low) may be a more advantageous factor in change than neighbourhood density. Moreover, it underscores that high density neighbourhoods may be least conducive to the process of change.

DISCUSSION

This study evaluated the role of lexical properties in productive sound change for insight to the problem of interword variation in phonological acquisition. By focusing specifically on the lexical variables of word frequency and neighbourhood density, it was possible to establish the relative influence of these in phonological generalization by children with functional phonological delays. The general findings across experimental conditions can be summarized using conventional notation of conditional reasoning, as in Table 4 (a–f).

TABLE 4. *Summary of results*

(a) HI frequency > LO frequency (b) HI frequency > HI density (c) LO density > HI density	where (e) HI frequency = LO density
(c) LO density > HI density (d) LO frequency > HI density	where (f) LO density ∨ LO frequency

Conditional notation: > greater than; = equal to; ∨ either or

With regard to the effects of word frequency, treatment results showed that both high and low frequency words enhanced change in children's productions. High frequency words induced greater generalization than either low frequency words (Table 4a) or high density neighbourhoods (b), and moreover, were equivalent to low density neighbourhoods (e). Notice that high frequency words consistently emerged as facilitating when paired with every other lexical property. Low frequency words did motivate change in some circumstances: namely, when they were in contrast to high or low density neighbourhoods (d and f, respectively). Apparently, the children of this study relied more heavily on the frequency characteristics of words when inducing change in the phonological system, rather than utilizing neighbourhood structure. Frequency thus emerged as a more salient variable in productive sound change.

With regard to neighbourhood structure, the treatment findings revealed that high density neighbourhoods were never a facilitating condition. High density neighbourhoods inhibited changes in children's productions when pitted against high and low frequency words (b and d, respectively), and against low density neighbourhoods (c). Therefore, the least facilitating condition to change relative to every other lexical variable was high density neighbourhoods. By these results, dense neighbourhood structure may be eschewed in developmental productive change. In comparison, low density neighbourhoods did show some enhancing effects on generalization, but only when in contrast to the disfavoured high density condition (c). Interestingly, low density was never completely independent of word frequency in its effects on productive sound change: it was either in an equivalent or a disjunctive relationship with frequency (e and f, respectively).

This study demonstrated the psycholinguistic reality of the properties of word frequency and neighbourhood density in production for children with phonological delays. That is, frequency and density seemed to affect the way in which the production of words may be modified phonologically by children. This was supported through systematic replications across experimental conditions, despite the relatively few subjects who presented with unique pretreatment phonological systems and who even received treatment on different target sounds. Moreover, the present study replicated, either directly or in part, the facilitating effects of frequency and density that have been reported for fully-developed systems and for normally developing systems. Table 5 integrates the findings across populations and across

TABLE 5. *Summary of facilitating lexical effects*

Phonological system	Lexical variables	Spoken word perception	Productive sound change
Fully-developed	Frequency	*HI*	*HI yields phonetic change*
	Density	*LO*	*HI resists change*
Developing			
Delayed	Frequency	No evidence	*HI > LO*
	Density	No evidence	*LO > HI*
			HI resists change
Normal	Frequency	*HI*	Mixed results
	Density	HI	No evidence

Parallels across populations are shown in italics.

production and perceptual domains. With reference to this, it can be seen that the production facts which emerged for children of this study were identical to the perceptual and production facts for adults. In addition, our findings paralleled the observed perceptual word frequency effects in normal phonological development, but were asymmetric to the expected density effects. Finally, there remain gaps in our understanding of the contributions of frequency and density across populations and domains of responding that warrant research attention. Together, these observations set the stage for possible associations between production and perception, children and adults, and normal and delayed development, and also serve to motivate continued descriptive and experimental investigations. With this in mind, two key questions will be directly addressed in discussion: why might word frequency be most salient in productive sound change? And, conversely, why might dense neighbourhood structure be avoided? These issues have implications for psycholinguistic models of processing and formal linguistic models of language structure.

Salience of word frequency

The positive effects of high frequency words on children's production accuracy are consistent with the evidence from spoken word perception for both normally developing children and adults. High frequency words are recognized more accurately and rapidly than low frequency words (e.g. Landauer & Streeter, 1973; Jusczyk, 1997). High frequency words are also produced more rapidly, and are resistant to speech errors by adults (e.g. Dell, 1990). In the present study, we extended these findings to additionally show that high frequency words facilitate productive change in phonological development.

Drawing from the psycholinguistic literature, one possible account of the salience of high frequency words has been attributed to the strength of the trace in memory associated with these words (McClelland & Elman, 1986; Dell, 1988). High frequency words occur often in the input, and consequently, the path to recognizing, accessing, retrieving, or producing them is well-worn. For the present findings, this explanation seems to fall short for at least two reasons. First, if the traces in memory to high frequency words are so strong, then these words should have been most resistant to change in treatment and in generalization. Yet, this was not the case. Secondly, we also found that low frequency words facilitated productive change in certain instances. If the facilitating effects of word frequency are due to the strength of the trace, then rarer words should not have had a comparable effect on change.

From the literature on normal language acquisition, another possible account of the salience of high frequency words relates to a child's need to be understood and to understand communication (Macken & Ferguson, 1983; Jusczyk, 1997). Perceptually, children may attend to high frequency words of the language in order to best discern a caregiver's message. Productively, children may articulate high frequency words most accurately because these would yield a clear and interpretable message to a listener. Again, this explanation cannot fully capture the results of this study. In particular, if a child's goal is to be understood, then not only should high frequency words be most salient to phonological change, but so should high density neighbourhoods. The reason is that accurate productions of words from dense neighbourhoods would prevent the occurrence of homonymy. The avoidance of homonymy for the sake of the communicative message has been a commonly reported production strategy that children (normal and delayed) seem to use (Macken & Ferguson, 1983; cf. Labov, 1994). On the contrary, this study demonstrated that high density neighbourhoods were the least facilitating condition to productive sound change. Consequently, a functional account associated with the social use of language may not be able to adequately address the observed word frequency effects.

As an alternative, it may be possible to reconcile the overall robustness of word frequency by appealing to the structural facts of historical linguistics. In particular, word frequency may yield differential effects depending on the type of productive sound change that is being introduced into the phonology. Recall that, in historical sound change, high frequency words changed first when a novel phonetic distinction was introduced in the language (Phillips, 1984). In comparison, low frequency words changed first when the change involved a new phonemic distinction. For fully-developed systems then, a different emphasis may be placed on word frequency depending on whether productive changes are phonetic or phonemic in nature. For normal and delayed development, phonetic change is a known precursor to phonemic change (Ferguson, Peizer & Weeks, 1973; Gierut *et al.*, 1994). A child begins introducing new sounds into the repertoire before these distinctions ever become functional contrastive units. If applied to the present results, we might expect that high frequency words would be more facilitative of change than low frequency words because of this phonetic precedence. Children may have been attracted to high frequency words in productive change out of the sheer necessity that a phonetic modification in productions had to first be instantiated before the corresponding phonemic change could be implemented. Similarly, word frequency (high or low) would be expected to be preferred overall relative to any conditions of neighbourhood density since any appeal to neighbourhood structure necessarily implicates minimal pairs, i.e. a phonemic contrast. The fact that both high and low frequency words had facilitating effects may therefore be attributable to the two different types of sound change – phonetic versus phonemic – that are associated with the split of a phonological category.

To test this proposal, it will be necessary for subsequent studies to establish whether the changes in a child's productions are, in fact, phonetic or phonemic. This will require that the lexical variables be examined relative to how the sounds undergoing change actually function in a child's grammar. Phonological data that are richer than the single-word generalization probes used in this study will be needed in order to discern minimal pair contrasts, segmental distributions, and potential free variations in children's productions. Toward this end, children with functional phonological delays may be a prime population of study, given the reported difficulty in establishing such facts for younger normals (Ferguson *et al.*, 1973). Moreover, if phonological data are collected longitudinally, it may be possible to observe that the emphasis on, and facilitating effects of, one lexical property will gradually shift to another as a child's phonological system advances in complexity. In complement, longitudinal descriptions of this type may best be obtained from normally developing children. Together, these research possibilities hold strong potential for a developmental characterization of how word frequency and neighbourhood density emerge and change over time in the production domain.

Avoidance of dense neighbourhoods

The limiting effects of high density neighbourhoods on production for children of this study directly parallel the evidence from spoken word perception for adults; however, the findings stand apart from observed perceptual patterns in phonological development. In perception, developing systems aim for establishing relatively dense neighbourhood structure in early word learning; whereas, in production, developing systems seem to eschew dense neighbourhood structure in sound change.

These developmental discrepancies associated with neighbourhood density in perception versus production are not likely to be attributable to considerations of age. Chronologically, children of this study were of comparable or younger ages than those of other perceptual reports. Differences in perception and production also cannot be traced to age of word learning (Walley & Metsala, 1990). Because children strive for dense neighbourhoods in perception, high density words will probably be earliest acquired. Given this, it might be thought that early acquired words in dense neighbourhoods will also be resistant to productive change since they may have the most longevity and stability. At first glance, this may seem a plausible reason for children's attraction to dense neighbourhoods in perception, as compared to their avoidance of dense neighbourhoods in production. This possibility becomes less tenable, however, when other experimental evidence is brought to bear. Namely, words which are first acquired have been shown to be first modified in children's productions (Tyler & Edwards, 1993).

For possible insight into the discrepant high density effects in perception versus production, it may be necessary to consider the qualitative nature of children's phonological representations. It has long been suggested from a range of theoretical perspectives that children may maintain non-ambient-like representations which structurally resemble their overt productive outputs (Dinnsen, 1998 for review). For example, if a child produces the word 'cat' as [tæt], and there is no evidence suggesting that /k/ is functionally contrastive in the phonological system, then the most concrete (albeit non-ambient) representation for this form would be /tæt/. There is a considerable body of evidence from both normal and delayed populations to support this proposal drawing upon substitution errors, differential segmental behaviour, variability, stimulability, acoustic evidence, learning, and diffuse lexical change (e.g. Gierut *et al.*, 1987; McGregor & Schwartz, 1992; Bernhardt & Stoel-Gammon, 1996; Dinnsen, 1996, 1998; Barlow, 1997). If it is the case that children's representations may be non-ambient, then this could potentially account for the avoidance of high density neighbourhoods. The reason is that many phonetically similar cohorts in the neighbourhood may, in fact, be represented identically. Consequently, a child may simply not know which of the words in the neighbourhood require a specific phonological change. For children with functional phonological delays, this effect may be particularly exacerbated given the extent of phonological mergers associated with an impoverished phonemic inventory.

To illustrate, consider the production patterns of Subject 11 of this study. This child was treated on the coronal /s/ in the low frequency condition, and the velar /g/ in the high density condition. One might have expected that since /g/ is earlier acquired according to developmental norms, it would have facilitated the greater change, yet it did not. However, for this child, target velars surfaced in production as coronals [t d]. If a concrete correspondence between production and representation is adopted, then target velars would have been represented by the child as /t d/. Importantly, following the concrete view, target coronal stops /t d/, non-strident fricatives /θ ð/, non-anterior fricatives /š ž/, and affricates /č ǰ/ would all also have been represented by Subject 11 as /t d/. This would potentially result in a 10-way representational merger. When this child was exposed to dense neighbourhood structure for productive sound change, multiple structurally-identical words would have been activated, hindering the search for which target words may have warranted the appropriate change. This hypothesis is consistent with general language processing models that claim the over-activation of lexical items slows search and retrieval (e.g. Dell, 1988). Alternatively, by this same hypothesis, it is also possible that structurally-identical words in dense neighbourhoods would have all changed simultaneously, albeit in the wrong direction, thereby still resulting in errors in production. Although overgeneralization was not observed for Subject 11, this scenario would predict that change in production of /g/ associated with the high density condition would have resulted in its erroneous overextension to other target words containing /t d θ ð š ž č ǰ/ because presumably they all would have been represented the same way by this child. Gross overgeneralizations of this type have indeed been reported in the developmental literature (Gierut, 1986, 1998). By comparison, similar representational confusions would not have resulted for the lexical variable of word frequency because the number of times a given word occurs in the input is independent of anything about its phonological structure.

A broad implication of this hypothesis is that the productive traits of a child's representations may not match identically to their perceptual characteristics. This could obtain by adopting a multi-levelled representational structure coded for (ambient) perception and (non-ambient) production (Iverson & Wheeler, 1987), or a two-lexicon model independent for perception and production (Menn & Matthei, 1992). The perception–production debate continues to be a source of controversy in the literature (Smolensky, 1996), but it may be especially relevant to certain subsets of children with phonological delays given documented asymmetries in perceptual and productive knowledge (McGregor & Schwartz, 1992 for perception > production but also production > perception). This notwithstanding, future research may need to consider lexical density in terms of a child's own unique grammar, with neighbourhood structure determined by the phonetic similarity of words that a child actually produces. This tact is comparable to the independent versus relational approaches to phonological analyses that have been advanced (Stoel-Gammon & Dunn, 1985). Comparisons of the effects of lexical properties which are independently determined, as opposed to those which are relationally derived may help to better establish the links between phonological and lexical structure, and perception and production in development.

Models of language processing

The results of this study bear certain similarities to recent research on adult spoken word production. For the most part, the lexical variables of word frequency and neighbourhood density have been examined almost exclusively in the perceptual domain. The few available production studies have focused on adult speech errors, and a word's vulnerability to either malopropisms or segmental slips (e.g. Dell, 1990; Vitevitch, 1997). Segmental slips are most relevant to the present data given our focus on children's speech sound errors. For adults, segmental slips occur least in high frequency words and in words from high density neighbourhoods. The latter parallels our finding demonstrating that high density neighbourhoods are immune to change for children. It is interesting to note, however, that the directionality of the sound change in the adult studies is just the reverse of that in this developmental study. For adults, the slip changes a production from correct to incorrect; whereas for children, the change is from an incorrect to a correct production. Nonetheless, it is striking that for both populations, dense neighbourhood structure appears to be impregnable to productive sound change.

The results from speech errors in adults have largely been interpreted within interactive, as opposed to serial models of processing (e.g. Dell, 1988). Within these, it has been necessary to posit two distinct levels of representational structure: a lexical level corresponding to the word, and a sublexical level corresponding to the sound (e.g. Vitevitch, 1997). Dual representational levels can accommodate the observed density effects in the speech errors of adults because the lexical activation of similar words apparently influences the activation of sublexical units. The differential activation of sublexical units leads to speech errors in words with certain neighbourhood characteristics, but not others. As the line of production research with adults continues to grow, it will be incumbent upon models of speech processing to incorporate developmental findings such as those reported here, and *vice versa*. This will afford the most comprehensive and continuous account of spoken word perception, production, and change over time.

Formal linguistic models

Finally, this investigation has the potential to contribute to current optimality theoretic approaches to the study of language, particularly as related to issues associated with phonological variability in acquisition. Optimality theory maps relationships between the target language input and a speaker's output through the rankings of constraints (McCarthy & Prince, 1994). Constraints are thought to be universal, but their rankings vary from language to language (or grammar to grammar). There are two types of constraints: faithfulness constraints and well-formedness constraints. FAITHFULNESS CONSTRAINTS preserve a direct correspondence of features, segments or sequences between the input and output. In comparison, WELL-FORMEDNESS CONSTRAINTS express markedness relationships, defining those features, segments or sequences that are to be explicitly avoided in the output. For early stages of acquisition, well-formedness constraints are thought generally to outrank faithfulness constraints. That is, a child is likely to be sensitive to general markedness considerations before attempting to maintain the specific characteristics of the input language. With development, faithfulness constraints eventually become higher-ranked. An important phenomenon that has been associated with the reranking of constraints (as in development) is EMERGENCE OF THE UNMARKED. These are instances when unmarked structures occur in the output, when in fact they should not, given the relative constraint ranking of the grammar. Emergence of the unmarked arises when faithfulness constraints dominate well-formedness constraints. Given this ranking, the effects of markedness associated with the low-ranked well-formedness constraints should not be apparent. That is to say, unmarked forms should not surface in the output. In most cases, this holds true. However, in the special case of emergence of the unmarked, unmarked outputs DO surface despite the fact that constraints dictating faithfulness to the input are higher-ranked. The end result is that a structurally marked input has a corresponding structurally unmarked output, despite the high ranking of faithfulness constraints. Emergence of the unmarked has been taken as crucial evidence in validating optimality theoretic accounts of grammar.

As applied to variation in acquisition, optimality theory has offered successful accounts of both interchild and intraword variability. Differences observed between children in their acquisition of the sound system have been handled by different rankings of constraints (Barlow, 1997). While constraints are universal, their initial ranking and subsequent promotion or demotion in development may differ by child, leading to the individual differences that are observed in outputs. Similarly, multiple productions of a given word have been dealt with by constraints being grouped into strata (Demuth, 1997). Those constraints belonging to a single stratum are left unranked relative to each other, forming a stratified domination hierarchy. Because constraints are unranked, a number of different outputs is equally possible, thereby permitting a range of productions of a single word. Given the present results, the application of optimality theory can be extended to further encompass instances of interword variation. By appealing to the lexical characteristics of word frequency and neighbourhood density, it may be possible to account for patterns of lexical diffusion in acquisition.

TABLE 6. *Proposed process of lexical diffusion*

Time	
↓	WELL-FORMEDNESS > > LEXICAL FAITHFULNESS
	FAITH[FREQ$_{HI}$] > > WELL-FORMEDNESS > > LEXICAL FAITHFULNESS
	FAITH[FREQ$_{HI}$], FAITH[DENS$_{LO}$], FAITH[FREQ$_{LO}$] > > WELL-FORMEDNESS > > FAITH[DENS$_{HI}$]
	LEXICAL FAITHFULNESS > > WELL-FORMEDNESS

Specifically, we propose a family of faithfulness constraints that are driven by the lexical structure of the input. LEXICAL FAITHFULNESS serves to maintain the phonological properties of target words with particular frequency and density characteristics. Based on our experimental findings, a possible set of constraints is:

FAITH[FREQ$_{HI}$]: The phonological properties of high frequency words of the input must be preserved.

FAITH[DENS$_{LO}$]: The phonological properties of words in low density neighbourhoods of the input must be preserved.

FAITH[FREQ$_{LO}$]: The phonological properties of low frequency words of the input must be preserved.

FAITH[DENS$_{HI}$]: The phonological properties of words in high density neighbourhoods of the input must be preserved.

The subsequent ranking of these constraints would be:

FAITH[FREQ$_{HI}$], FAITH[DENS$_{LO}$], FAITH[FREQ$_{LO}$] > > FAITH[DENS$_{HI}$].

Notice that the first three constraints are unranked relative to each other, as denoted by intervening commas. This is because of their equivalent or disjunctive relationship in inducing productive sound change for the children of this study. Given its consistently negative effects on change, FAITH[DENS$_{HI}$] is lowest-ranked, as denoted by the double right-angle brackets. Importantly, this family of lexical constraints differs from other faithfulness constraints that have been advanced in the literature because these do not derive purely from the phonological characteristics of features, segments, or syllables. Instead, lexical facts served to motivate the constraints. It seems plausible to incorporate lexical considerations directly into the grammar in light of other recent optimality proposals, whereby the syntactic properties of words (i.e. NOUN FAITHFULNESS in normal phonological acquisition, Smith, 1998) and input frequency (Boersma, 1997) have been suggested to account for phonological patterns.

As depicted in Table 6, the process of lexical diffusion may begin with these lexical constraints in addition to other well-formedness constraints that restrict certain segments in a child's output, e.g. *Fricatives militating against the occurrence of fricatives. Consistent with the predominant view of acquisition, well-formedness constraints may dominate lexical faithfulness constraints. At this point, certain segments (in this example, fricatives) will be prevented from occurring in the output, regardless of the lexical properties of words.

With the implementation of sound change, there will be an explosion of the family of lexical constraints. It is likely that Faith[FREQ_{HI}] will be promoted first over well-formedness and all other constraints in the lexical family. This follows from our experimental finding that high frequency consistently enhanced productive sound change. The promotion of Faith[FREQ_{HI}] would result in target sounds being produced in some, but not all relevant target words. In our example, fricatives would occur in high frequency words, but not in words with other lexical properties. Importantly, this constitutes emergence of the unmarked. The reason is that Faith[FREQ_{HI}] outranks the well-formedness constraint disfavouring fricatives. By this ranking of faithfulness over well-formedness, fricatives should occur but, in fact, they still do not surface in all cases. This potentially explains children's interword variability.

As the process of diffusion proceeds, Faith[DENS_{LO}] and/or Faith[FREQ_{LO}] will be promoted. At this stage, there will be an increasing number of target words containing the emerging sound which will be produced correctly. Then, in the final stages of lexical diffusion, the entire family of lexical faithfulness constraints will come to dominate well-formedness constraints, and all relevant words will be produced target-appropriately. By this account, the process of lexical diffusion may best be characterized as a well-defined case of emergence of the unmarked.

This specific application of optimality theory to lexical diffusion requires empirical validation across language-learning populations. The sequential order in which children's production of words changes from correct to incorrect will need to be documented longitudinally. From this, the lexical characteristics of the specific words that changed could actually be determined. For example, do high frequency words, in fact, change first in children's productions, and do words from high density neighbourhoods change last? In addition, it will be important to compare lexical diffusion by normal children versus those with phonological delays to determine if the same relative constraint ranking holds generally across developing systems. Extending this, cross-linguistic investigations of systems undergoing sound change will help to establish if the proposed ranking of lexical constraints may be harmonic (i.e. universal), or if the ranking may vary language by language resulting in factorial typologies. Descriptive studies of this sort are necessary extensions of this initial attempt to establish whether and which lexical conditions may prompt productive sound change in development.

CONCLUSION

The lexical properties of word frequency and neighbourhood density hold potential in accounting for long-standing questions about individual differences in phonological acquisition, particularly as related to children's interword variation in productions. This preliminary experimental investigation demonstrated that interword variability in acquisition may be attributable to the lexical characteristics of target words. In particular, word frequency emerged as the most salient factor in promoting productive sound change, whereas dense neighbourhood structure appeared to be most restrictive. This general line of study parallels research in the perceptual domain for developing and fully-developed systems, and offers a means of integrating production and perception across populations. It also has implications for psycholinguistic and linguistic models in that the data which derive from the developmental study of lexical variables will ultimately need to be incorporated into formal proposals for a comprehensive account of the interface between the phonology and the lexicon.

REFERENCES

Barlow, J. A. (1997). *A constraint-based account of syllable onsets: evidence from developing systems*. Unpublished doctoral dissertation, Indiana University, Bloomington.

Bernhardt, B. & Stoel-Gammon, C. (1996). Underspecification and markedness in normal and disordered phonological development. In C. E. Johnson & J. H. V. Gilbert (eds), *Children's language*. Mahwah, NJ: Erlbaum.

Bernhardt, B., Gilbert, J. & Ingram, D. (eds) (1996). *Proceedings of the UBC International Conference on Phonological Acquisition*. Somerville, MA: Cascadilla Press.

Boersma, P. (1997). *How we learn variation, optionality, and probability*. Rutgers Optimality Archives no. 221–1097.

Dell, G. S. (1988). The retrieval of phonological forms in production: tests of predictions from a connectionist model. *Journal of Memory and Language* **27**, 124–42.

Dell, G. S. (1990). Effects of frequency and vocabulary type on phonological speech errors. *Language and Cognitive Processses* **5**, 313–49.

Demuth, K. (1997). Multiple optimal outputs in acquisition. *University of Maryland Working Papers in Linguistics* **5**, 53–71.

Dinnsen, D. A. (1996). Context-sensitive underspecification and the acquisition of phonemic contrasts. *Journal of Child Language* **23**, 57–79.

Dinnsen, D. A. (1998). Some empirical and theoretical issues is disordered child phonology. In P. K. Bhatia & W. C. Ritchie (eds), *Handbook on child language acquisition*. NY: Academic Press.

Ferguson, C. A., Peizer, D. B. & Weeks, T. E. (1973). Model-and-replica phonological grammar of a child's first words. *Lingua* **31**, 35–65.

Gierut, J. A. (1986). Sound change: a phonemic split in a misarticulating child. *Applied Psycholinguistics* **7**, 57–68.

Gierut, J. A. (1998). Production, conceptualization and change in distinctive featural categories. *Journal of Child Language* **25**, 321–42.

Gierut, J. A., Elbert, M. & Dinnsen, D. A. (1987). A functional analysis of phonological knowledge and generalization learning in misarticulating children. *Journal of Speech and Hearing Research* **30**, 462–79.

Gierut, J. A., Morrisette, M. L., Hughes, M. T. & Rowland, S. (1996). Phonological treatment efficacy and developmental norms. *Language, Speech, and Hearing Services in Schools* **27**, 215–30.

Gierut, J. A., Simmerman, C. L. & Neumann, H. J. (1994). Phonemic structures of delayed phonological systems. *Journal of Child Language* **21**, 291–316.

Ingram, D. (1979). Cross-linguistic evidence on the extent and limit of individual variation in phonological development. *Proceedings of the 9th International Congress of Phonetic Sciences* **2**, 150–4.

Ingram, D. (1989). *Phonological disability in children*. Second edition. London: Cole and Whurr.

Iverson, G. K. & Wheeler, D. (1987). Hierarchical structures in child phonology. *Lingua* **73**, 243–57.

Jakobson, R. (1941/1968). *Child language, aphasia and phonological universals*. (A. R. Keiler, trans.). The Hague, Netherlands: Mouton.

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

Kelly, M. H. & Martin, S. (1994). Domain-general abilities applied to domain-specific tasks: sensitivities to probabilities in perception, cognition, and language. In L. Gleitman & B. Landau (eds), *The acquisition of the lexicon*. Cambridge, MA: MIT Press.

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

Labov, W. (1994). *Principles of linguistic change: internal factors*. Cambridge, MA: Blackwell.

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**, 119–31.

Leonard, L. B. & Ritterman, S. I. (1971). Articulation of /s/ as a function of cluster and word frequency of occurrence. *Journal of Speech and Hearing Research* **14**, 476–85.

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

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

Macken, M. A. & Ferguson, C. A. (1983). Cognitive aspects of phonological development: model, evidence, and issues. In K. E. Nelson (ed.), *Children's language*. Hillsdale, NJ: Erlbaum.

McCarthy, J. J. & Prince, A. S. (1994). The emergence of the unmarked: optimality in prosodic morphology. *Northeastern Linguistic Society* **24**, 333–79.

McClelland, J. L. & Elman, J. L. (1986). The TRACE model of speech perception. *Cognitive Psychology* **18**, 1–86.

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

McReynolds, L. V. & Kearns, K. P. (1983). *Single-subject experimental designs in communicative disorders*. Baltimore: University Park Press.

Menn, L. & Matthei, E. H. (1992). The 'two-lexicon' account of child phonology: looking back, looking ahead. In C. A. Ferguson, L. Menn & C. Stoel-Gammon (eds), *Phonological development: models, research, implications*. Timonium, MD: York Press.

Moore, W. H., Burke, J. & Adams, C. (1976). The effects of stimulability on the articulation of /s/ relative to cluster and word frequency of occurrence. *Journal of Speech and Hearing Research* **19**, 458–66.

Nusbaum, H. C., Pisoni, D. B. & Davis, C. K. (1984). Sizing up the Hoosier mental lexicon. *Research on Speech Perception* **10**, 409–22.

Phillips, B. S. (1984). Word frequency and the actuation of sound change. *Language* **60**, 320–42.

Psychological Corporation (1995). *Picture gallery*. San Antonio: Harcourt Brace & Company.

Smith, J. (1998). *Noun faithfulness: on the privileged behavior of nouns in phonology*. Rutgers Optimality Archives #242–0198.

Smith, N. V. (1973). *The acquisition of phonology : a case study*. Cambridge: C.U.P.
Smolensky. P. (1996). On the comprehension/production dilemma in child language. *Linguistic Inquiry* **27**, 720–731.
Stoel-Gammon, C. & Dunn, C. (1985). *Normal and disordered phonology in children*. Austin, TX: Pro-Ed.
Tyler, A. A. & Edwards, M. L. (1993). Lexical acquisition and acquisition of initial voiceless stops. *Journal of Child Language* **20**, 253–73.
Vitevitch, M. S. (1997). The neighborhood characteristics of malapropisms. *Language and Speech* **40**, 211–28.
Walley, A. C. & Metsala, J. L. (1990). The growth of lexical constraints on spoken word recognition. *Perception & Psychophysics* **47**, 267–80.