Syllable Onsets: Clusters and Adjuncts in Acquisition

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The Sonority Sequencing Principle is a presumed universal that governs the permissible sequences of consonants within syllables. In two single-subject experiments, we evaluated this principle as applied to the acquisition of onset clusters and adjuncts by children exhibiting functional phonological delays (age in years;months: 3;2 to 7;8). Experiment 1 tested the hypothesis that children abide by the Sonority Sequencing Principle in development, such that the occurrence and use of marked true clusters implies unmarked clusters, but not vice versa. This claim was validated, in part, by the gradient generalization learning patterns of children who were taught marked clusters. Others who were taught unmarked clusters exhibited limited learning characteristic of within-class generalization, with apparent gaps in sonority sequencing. Experiment 2 examined the role of adjunct sequences /sp, st, sk/, whose markedness status is questionable given their violation of the Sonority Sequencing Principle. Results indicated that children learned adjuncts consistent with patterns of within-class generalization, thereby supporting the view that these sequences are unmarked in structure. Experimental findings are integrated in discussion of the representation of onset clusters and their course of emergence in phonological acquisition relative to the Sonority Sequencing Principle.

KEY WORDS: syllable, sonority, consonant cluster, language acquisition, phonological disorders

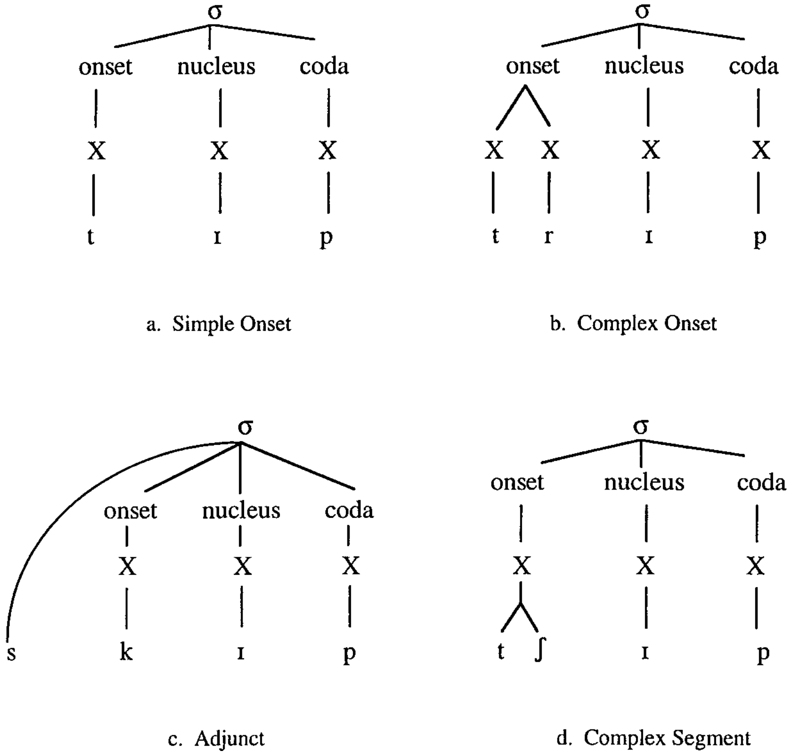
A fundamental structure in the hierarchical organization of word-level phonology is the syllable. There is broad linguistic and psycholinguistic evidence in support of the syllable as a representational unit in fully developed linguistic systems (e.g., Kahn, 1980; Levin, 1985; Selkirk, 1982; Steriade, 1990; for a basic introduction, see Blevins, 1995 or Kenstowicz, 1994). There is also mounting evidence that the syllable is a salient and crucial unit in developing linguistic systems as well. In speech perception, infants prefer to parse a continuous speech stream on the basis of syllable-sized units (Jusczyk, 1997 and references therein). In speech production, children in the early stages of babbling are more likely to experiment with new segments in the context of stable syllabic frames (MacNeilage & Davis, 1990). The focus on the syllable continues throughout mastery of ambient-like productions, with children modifying and improving their vocal motor schemes consistent with consonant-vowel units (Nittrouer & Studdert-Kennedy, 1987; Nittrouer, Studdert-Kennedy, & McGowan, 1989; Nittrouer, Studdert-Kennedy, & Neely, 1996). In metalinguistic processing, preliterate children are aware that words consist of smaller units corresponding to the syllable, even before they are able to identify the precise number or nature of segments involved (Treiman & Baron, 1981; Treiman & Breaux, 1982).

Despite the prominence of the syllable for fully developed and developing systems, relatively little is known about how syllabic structure is actually acquired. This paper examines the learning process, particularly with regard to the acquisition of syllable onsets. Syllable onsets are of primary concern for two reasons. First, the onset as a relevant constituent of the syllable is relatively undisputed, as compared to other presumed components of syllabic structure (Davis, 1988; Hockett, 1955). (The reader should compare models of syllable-internal structure associated with flat structure: Clements & Keyser, 1983; binary branching structure with body: McCarthy, 1979; or rime: Selkirk, 1982; and moraic approaches: Hayes, 1989.) Second, the onset—namely, complex onsets involving consonant clusters—is a prevalent source of difficulty and is frequently in error in young children's productions (Freitas, 1996; Ingram, 1978, 1989; McLeod, van Doorn, & Reed, 1997; Smit, 1993). The focus on onsets thus allows for an examination of perhaps the most stable property of the syllable, yet one that is extremely vulnerable in the acquisition course.

By way of overview, the syllable is generally thought to consist of three constituents: the onset, nucleus or vowel, and the coda, as depicted in Figure 1(a). All syllables must have a nucleus, but the presence of an onset or a coda may be optional. Further, as in Figure 1(b), onsets or codas may involve complex branching structure, as in the occurrence of consonant clusters. Importantly, when onsets or codas occur in syllabic structure, and particularly when they involve branching structure, they are governed by a higher-order property of language known as the *Sonority Sequencing Principle* (Clements, 1990). This principle states that onsets of syllables maximally rise in sonority to the nucleus, and codas fall (or remain level) in sonority from the nucleus. Sonority refers to a resonant property that roughly corresponds with degree of constriction (Chin, 1996).[1] In other words, the segments of a syllable arrange in sequence from most constricted to most unconstricted as they reach the vowel peak; and following the peak, the sequence is just the reverse. The Sonority Sequencing Principle thus determines what constitutes a possible syllable, in general, and a possible onset, in particular.

The Sonority Sequencing Principle derives from observations of a more general *sonority hierarchy*, first reported by Sievers in 1881 with subsequent cross-linguistic instantiation (Clements, 1990; Giegerich, 1992;

Figure 1. Representations of syllable structure.



a. Simple Onset

b. Complex Onset

c. Adjunct

d. Complex Segment

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[1] A single and direct phonetic correlate to the phonological property of sonority has yet to be determined or agreed upon. Consequently, a number of definitions of sonority have emerged in the literature. They include, for example, degree of loudness (Ladefoged, 1982), airflow (Giegerich, 1992), or combinations of distinctive features (Clements, 1990). In the present paper, the term *sonority* is used to describe the phonological patterning of syllables and not the physical implementation of sonority. For a discussion of observed differences between the phonetic and phonological characteristics of sonority, the reader is referred to Blevins (1995), Ladefoged (1982), and McCarthy (1986).

Jespersen, 1904). The sonority hierarchy is a rank-ordering of the sonority values of sound classes on a numerical scale. Following Steriade (1990), a possible expanded ranking with corresponding numerical values from least- to most-sonorous segments follows: voiceless stops (7), voiced stops (6), voiceless fricatives (5), voiced fricatives (4), nasals (3), liquids (2), glides (1), and vowels. This scale can be applied to any given language to calculate the difference in sonority between sequences of segments in onset position. For example, given the word *trip*, the sonority difference between the segments of the onset cluster /tr/ is 5; namely, the voiceless stop /t/ with a value of 7 minus the liquid /r/ with a value of 2 yields the difference, 5. As another example, the onset cluster of the word *bloom* has a sonority difference of 4; the voiced stop /b/ with a value of 6 minus the liquid /l/ with a value of 2 yields the difference, 4. By applying the sonority hierarchy, it is possible to compute the *sonority difference* between every sequence of segments that is allowed in a language in onset position.

The Sonority Sequencing Principle has been further extended to identify implicational relationships involving sonority (Davis, 1990; Steriade, 1990). If a language allows sequences of a small sonority difference in onset position, it will also allow those with greater sonority differences, but not vice versa. In other words, the smaller the sonority difference, the more marked the consonant cluster. For English, the most marked onset clusters are voiceless fricative + nasal sequences /sm, sn/, with a sonority difference of 2. As predicted from the Sonority Sequencing Principle, the occurrence of a small sonority difference implies the occurrence of all greater differences, and English is no exception. It also permits sonority differences of 3 (e.g., voiceless fricative + liquid), 4 (e.g., voiced stop + liquid), 5 (e.g., voiceless stop + liquid), and 6 (e.g., voiceless stop + glide), with the latter being the most unmarked cluster type.

Although the Sonority Sequencing Principle is claimed to be robust (Clements, 1990; Giegerich, 1992; Kenstowicz, 1994), there is a well-defined exception in English associated with the voiceless fricative + stop clusters /sp, st, sk/. In these cases, the more sonorous fricative precedes the less sonorous stop. This represents an apparent violation of the Sonority Sequencing Principle and has been the subject of much debate, particularly with regard to the markedness value of sC sequences (Giegerich, 1992; Goldsmith, 1990; Harris, 1994; Selkirk, 1982). On the one hand, these clusters appear to be highly marked because their sonority difference is –2 (voiceless fricative [5] minus voiceless stop [7]). On the other hand, this inherent violation of the Sonority Sequencing Principle itself suggests that these sequences may not really be clusters at all, independent of anything about their sonority difference. Of the two markedness perspectives, the more prominent is that sC sequences are not clusters but, rather, that /s/ is adjunct to a simple onset, as depicted in Figure 1(c) (Davis, 1990, 1992; Giegerich, 1992; Kenstowicz, 1994). Evidence in support of /s/ as an adjunct (or, alternatively, an "appendix" following Selkirk, 1982) comes additionally from the fact that these sequences violate other word-initial English phonotactics including, for example, the nonoccurrence of homorganic clusters (e.g., */pw/ but /st/), obstruent + nasal sequences (e.g., */pn/ but /sn/), and obstruent + obstruent sequences (e.g., */ft/ but /st/). Native speakers' intuitions about syllabification of sC sequences (Clements & Keyser, 1983) and other cross-linguistic observations (Carr, 1993; Davis, 1990; Kenstowicz, 1994; Kim, 1990; Steriade, 1988) further bolster the adjunct argument. For purposes of the present discussion, we will use the terms *true cluster* and *adjunct cluster* to differentiate between onset sequences that conform to and those that violate the Sonority Sequencing Principle, without adopting a priori a theoretical stance about markedness.

These linguistic observations and hypotheses serve to motivate the questions to be addressed in Experiments 1 and 2. Namely, do children abide by and conform to the Sonority Sequencing Principle in acquisition of onset clusters? And, what is the status of sC sequences in the course of phonological learning?

Experiment 1

Few reports have examined how children learn to produce onset consonant clusters. The available descriptive studies have focused on the acoustic phonetic properties and substitution errors in cluster production by normally developing and phonologically delayed children (Allerton, 1976; Catts & Kamhi, 1984; Chin & Dinnsen, 1992; Greenlee, 1974; Kornfeld, 1971; McLeod et al., 1997; Menyuk, 1972; Menyuk & Klatt, 1968, 1975; Smit, 1993). The intent was to identify cross-sectional ages of acquisition and developmental stages in the progression from production of 1- to 2-element consonantal sequences. Other investigations explored children's implicit knowledge of onset consonant clusters (Barton, Miller, & Macken, 1980; Lance, Swanson, & Peterson, 1997). The purpose here was to gain insight into a child's sensitivities to the phonological characteristics of clusters (without also requiring explicit productions) as a reflection of their phonological capabilities.

In comparison with these approaches, some experimental studies have directly emphasized learning in the manipulation of clusters in clinical treatment for children with phonological delays. From the experimental treatment studies, two primary accounts of cluster acquisition have been put forth, but neither invoked the

Sonority Sequencing Principle. A first, and the more classical view, appeals to standard principles of learning associated with *within-class generalization*. The basic premise is that clusters that share a common segment form a natural class, thereby facilitating generalization and change in children's productions (Elbert & McReynolds, 1975, 1979; McReynolds & Elbert, 1981; Tyler, Edwards, & Saxman, 1987; Williams, 1988; Young, 1987). One difficulty with this view is that not all target clusters can be unambiguously classified. For instance, in the case of /sl/, it is unclear whether this sequence forms a natural class with other sC clusters such as /sm, sn/, with other Cl clusters such as /pl, gl/, or with both. The subsequent impact of dual classification on phonological learning is unclear.

An alternate view is consistent with a linguistic principle of *sequential markedness* (Clements, 1990). If segment B is marked relative to segment A, then the sequence xBx is, in turn, more marked relative to xAx. Consistent with experimental treatment manipulations of markedness, the claim is that treatment of marked sequences will facilitate change in unmarked sequences, but not vice versa (Elbert, Dinnsen, & Powell, 1984; Powell & Elbert, 1984). As with within-class generalization, this perspective also has indeterminacies because it does not capture overlapping markedness relationships among various cluster types. To illustrate, two well-known markedness relationships are that fricatives imply stops and that liquids imply nasals, but not vice versa. Following from sequential markedness, a cluster like /f̲l/ is presumably marked relative to /p̲l/; similarly, /sl̲/ is apparently marked relative to /sn̲/. Yet, what is the markedness relationship between /pl/ and /sn/? On the one hand, /s̲n/ should be more marked relative to /p̲l/ given the association between fricatives and stops. On the other hand, /pl̲/ should be more marked relative to /sn̲/ given the status of liquids to nasals. These ambiguities again make it difficult to predict the direction of acquisition or change in cluster production.

Importantly, the Sonority Sequencing Principle offers a potential resolution to limitations of the prior accounts. In particular, the Sonority Sequencing Principle defines natural classes of clusters on the basis of sonority difference, not on the commonalty of segmental elements. Clusters that are segmentally similar may, in fact, be quite different in terms of their sonority difference. To illustrate, the clusters /pl, bl, fl/ all involve Cl sequences, but these vary in sonority differences, ranging from 5 to 3, respectively. The cluster /pl/ is less marked (and therefore should be easier to learn) than /bl/, which, in turn, is less marked than /fl/. A reverse situation likewise obtains: Clusters that are unique in their segmental composition may be identical in sonority difference. A relevant example is that of /sw/ and /bl/. These clusters do not have any segments in common, yet both have a sonority difference of 4. The Sonority Sequencing Principle is also preferred over sequential markedness because it independently identifies markedness relationships across various cluster types. Simply, the smaller the sonority difference, the more marked the cluster. If we return to the seemingly indeterminate relationship between /pl/ and /sn/ cited above, the Sonority Sequencing Principle clearly establishes /sn/ as more marked, given its sonority difference of 2, than /pl/, with a sonority difference of 5.

In Experiment 1, we put the Sonority Sequencing Principle to test as a cohesive account of cluster acquisition by manipulating it in experimental clinical treatment and determining whether children conform to its predictions. We hypothesized that children who acquired clusters with a marked sonority difference following treatment would also master clusters of all unmarked sonority differences, but not vice versa. Following from prior markedness manipulations (e.g., Dinnsen & Elbert, 1984; Elbert et al., 1984; Elbert & McReynolds, 1978; Gallagher & Shriner, 1975; McReynolds & Jetzke, 1986; Rockman, 1983; Tyler & Figurski, 1994; for review, see also Gierut, 1998b; Gierut, Morrisette, Hughes, & Rowland, 1996), we further expected that experimental treatment directed at marked sonority differences would result in more extensive change in cluster production than treatment of unmarked sonority values.

Method

Participants

Six children with functional phonological delays, ages 3;2 to 7;8 (years;months), participated. Children were recruited from local schools and preschools in response to a general announcement and were selected following a comprehensive diagnostic evaluation of their speech, language, and hearing abilities. All children exhibited normal hearing (ASHA, 1985), oral-motor structure and function (Robbins & Klee, 1987), nonverbal intelligence (Levine, 1986), and age-appropriate expressive/receptive language (Dunn & Dunn, 1981; Hresko, Reid, & Hammill, 1981; Newcomer & Hammill, 1988) as determined by their performance on the aforereferenced standardized measures. Children resided in monolingual English-speaking homes and had no prior or concurrent phonological treatment as established by parent report.

Phonological Analyses

Children were required to exhibit broad-based errors in production of target singletons and onset clusters as based on relational and independent analyses. Relational analyses directly compare the accuracy of a child's productions to the adult standard, whereas independent analyses evaluate a child's productions as a self-contained linguistic system (Stoel-Gammon & Dunn, 1985). Converging evidence from relational and independent analyses is thought to provide a complete picture of a child's phonological system because it establishes what a child knows about the ambient language (albeit correct or incorrect) and what still remains to be learned. For purposes of this study, relational analyses confirmed that a child had a phonological disorder, in general, and that target onset clusters were not accurately produced, in particular. Independent analyses further revealed whether a child had knowledge of sonority relationships in the absence of target-appropriate cluster productions. Because prior studies have shown that such knowledge may influence performance in treatment, the results of the independent analyses were used expressly in experimental assignments (cf. Dinnsen & Elbert, 1984; Gierut, Elbert, & Dinnsen, 1987; Tyler, Edwards, & Saxman, 1990).

With regard to singletons, from a relational perspective, children were required to perform at or below the 7th percentile on the Goldman-Fristoe Test of Articulation Sounds-in-Words Subtest (Goldman & Fristoe, 1986) relative to age- and gender-matched peers. From an independent perspective, children were to exclude a minimum of seven target English consonants from their phonemic inventory, as tested on the Phonological Knowledge Protocol (Gierut, 1985) and as based on minimal pair criteria (Gierut, Simmerman, & Neumann, 1994). The Phonological Knowledge Protocol consists of 198 pictured items that sample all ambient English consonants in each relevant word position in a minimum of five different exemplars. The Protocol provides opportunities for production of potential minimal pairs and morphophonemic alternations. Together these analyses of target singletons were used to initially establish that a child's consonantal repertoire was severely impoverished, contributing to extreme unintelligibility, and that phonological treatment was warranted to induce positive changes in production.

With regard to onset clusters, from a relational perspective, children were to produce target clusters with near 0% accuracy on a 146-item probe that was spontaneously elicited through picture-naming (Gierut, 1998a). This probe sampled all ambient clusters and all sonority differences, with at least 25 exemplars per cluster type. From an independent perspective, the probe responses were further used to establish the permissible and minimal sonority differences in each child's phonological system. Following from the Sonority Sequencing Principle and with reference to Steriade's (1990) expanded sonority scale, a child was credited with a particular sonority difference if there was a two-time occurrence of that value, whether or not correct relative to the input. The two-occurrence criterion was modeled after Stoel-Gammon (1985) and Dinnsen, Chin, Elbert, and Powell (1990) for establishing children's phonetic inventories and after Gierut et al. (1994) for determining children's phonemic inventories. For example, if the nonambient cluster [fw] was produced twice on the onset cluster probe, as in [fwi] *three* and [fwaɪ] *fly*, then a child would be credited with the sonority value of 4. The smallest sonority difference allowed in a child's phonological system was taken to be the *minimal distance* (Clements, 1990). Typical nonambient clusters that were produced by children of this study were [pw], [bw], and [fw]; Subject 3 was the only child to produce ambient clusters [sm, sn, sp, st, sk], but these were not necessarily used target-appropriately (e.g., [sn] for target /sl/, [sk] for targets /tr, kl, sp/). Jointly, these cluster analyses confirmed near 0% baseline levels of performance for the experimental manipulations and established the minimal distance for use in selection of the target cluster to be taught. Table 1 lists the target phonemes excluded from each child's pretreatment consonantal inventory and the minimal sonority distance allowed.

Experimental Design and Treatment Procedures

Children were pseudorandomly assigned to one of two experimental conditions within the context of a single-subject, staggered, multiple-baseline design (McReynolds & Kearns, 1983). This design provides a baseline period of no-treatment followed by treatment, with the number of baselines increasing by one as each successive child is enrolled. The basic premise is that baseline performance within and across children will remain stable and unchanged until the instatement of treatment; thus, any improvements in performance are directly attributable to the treatment itself. The effects of treatment are established through replication, with each subject serving as his or her own control, rather than assuming homogeneity of the population for statistical purposes.

In this experiment, the relevant baseline measure was the probe of onset clusters. As noted, children produced and maintained near 0% baseline accuracy of ambient clusters before treatment. Treatment itself involved imitation, followed by spontaneous production of a given target cluster presented in the onset position of nonwords. Nonwords were used because they provided a means of controlling for word frequency, neighborhood density, age of acquisition, and teaching context and stimuli across children. Nonwords have been demonstrated to facilitate phonological acquisition in that they introduce new, rather than attempt to change existing, sound patterns (MacWhinney, 1985; Slobin, 1971), and production accuracy is enhanced (Bryan & Howard,

Table 1. Subject characteristics.

			Independent phonological analyses pretreatment		
Subject	Age	Gender	Phonemes excluded	Minimal distance and example of cluster produced	Experimental assignment
1	3;2	F	ŋ θ ð š č ǰ l r j	4, with use of [fw]	Experiment 1
2	4;2	M	t d θ ð š č ǰ l r	4, with use of [fw]	Experiment 1
3	6;10	M	ŋ θ ð š č l r j	2 (or less), with use of [sm, sn, sp, st, sk]	Experiments 1 and 2B
4	5;11	M	v θ ð z š č ǰ l r	4, with use of [fw]	Experiment 1
5	7;8	M	ŋ θ ð s z š l r	5, with use of [bw]	Experiment 1
6	3;8	M	ŋ k g f v θ ð s z š č ǰ l r h	—	Experiments 1 and 2A
7	4;8	M	f v θ ð s z š l r	—	Experiment 2A
8	3;9	M	θ ð š č ǰ l r h	2 (or less), with use of [sm, sn, sp, st, sk]	Experiment 2B
9	4;2	M	f v θ ð s z š č ǰ l	4, with use of [dr]	Experiment 2C
10	3;5	M	v θ ð s z l r	4, with use of [sw]	Experiment 2C
11	4;0	F	f v s z š č ǰ l r j	4, with use of [θw]	Experiment 2C

Note. For Subjects 6 and 7, no ambient or nonambient clusters were produced, as denoted by a dash.

1992; Elbert & McReynolds, 1978; Kiernan & Swisher, 1990; Leonard, Schwartz, Folger, & Wilcox, 1978). In this study, 15 nonwords were introduced in treatment, with these being phonotactically permissible sequences balanced for canonical structure, phonetic environment, and syntactic category. More specifically, nonwords took the shapes CCVC (n = 7 forms), CCVCV (n = 4 forms), and CCVCVC (n = 4 forms). This allowed for the nonword stimuli to include both closed and open syllables and mono- and multisyllabic forms. The initial CC sequence always corresponded to that onset target cluster being treated for a given child. The following Vs were varied across nonwords to represent the full vowel space, namely, /i, e, ɛ, æ, ɑ, ʌ, o, u/. Subsequent Cs in the nonwords were limited to /m, n, b, d/, balancing labial and coronal places of articulation. Eight of the nonwords were nouns and seven were verbs, with lexical meaning being assigned through an established story-telling paradigm (Gierut, 1992). That is, nonwords were introduced in picture-book stories involving imaginative characters performing unusual actions, antics, or acrobatics. Storybooks were shown and read to a child each week of treatment. The pictured nonword stimuli were extracted from these stories and displayed on flash cards for use in production practice. Production practice was implemented using a recommended drill-play format (Shriberg & Kwiatkowski, 1982), with the employment of such varied activities as matching, sorting, or informal story retelling.

Treatment of nonwords was provided to a child three times weekly in 1-hour sessions. Treatment continued to preestablished time- or performance-based criteria. During the imitation phase, a child was required to repeat the nonwords following the experimenter's verbal model with 75% accuracy over two consecutive sessions or until seven total sessions were completed, whichever occurred first. Treatment then shifted to the spontaneous phase, whereby a child produced the pictured nonwords without a verbal model with 90% accuracy over three consecutive sessions or until 12 total sessions were completed, whichever occurred first. In both training phases, 1:1 feedback as to the accuracy of cluster production in the nonwords was provided. In this study, the majority of children (4 of 6) followed the time-based criterion during the imitation phase but followed the performance-based criterion during the spontaneous phase of treatment. All children evidenced improvement in production of the treated cluster in the nonword stimuli, with performance ranging from 51 to 94% accuracy in imitation, and 78 to 98% accuracy in spontaneous production.

Independent and Dependent Variables

The Sonority Sequencing Principle was manipulated in treatment in two key ways. First, the markedness value of the treated cluster was varied, such that 3 children were taught more marked clusters relative to their own pretreatment minimal distance, and 3 others were taught unmarked clusters. Second, within each condition, the degree of (un)markedness varied incrementally in step-sizes of 1, 2, or 3 relative to a child's pretreatment minimal distance. This was intended to constrain the particular type of cluster that would be taught relative to a child's entry knowledge of sonority relationships.

To illustrate these manipulations, Table 2 shows the pretreatment minimal distance, treated sonority difference, treated cluster, and its pretreatment substitute

Table 2. Experimental assignments for Experiment 1.

Subject	Pretreatment minimal distance	Markedness	Markedness increment	Treated sonority difference	Treated cluster	Pretreatment substitute
1	4	Unmarked	1	5	/kl/	[k]
2	4	Unmarked	2	6	/kw/	[k]
3	2	Unmarked	3	5	/pr/	[p]
4	4	Marked	1	3	/fl/	[f]
5	5	Marked	2	3	/fl/	[f]
6	—	Marked	3	4	/bl/	[b]

for each child by condition. Consider Subject 4 whose pretreatment minimal distance was 4. This child was assigned to the marked treatment condition with a step-size increment of 1. Recall that the smaller the sonority value, the more marked the cluster. Consequently, for this child, the treated cluster was to be of a smaller sonority difference that was reduced by 1. Hence, Subject 4 was treated on a more marked cluster of the sonority difference 3 (i.e., pretreatment minimal distance of 4 minus a step-size of 1 resulted in the treated sonority difference of 3). As another example, Subject 5 had a pretreatment minimal distance of 5 and was also assigned to the marked treatment condition. Like Subject 4, this child received treatment on the sonority difference 3; however, this corresponded to a step-size increment of 2 relative to the child's pretreatment minimal distance (i.e., pretreatment minimal distance of 5 minus a step-size of 2 yielded the treated sonority difference of 3).[2] These same procedures applied for Subject 6, for whom a marked sonority difference was selected with a step-size increment of 3 relative to the pretreatment minimal distance. In the alternate unmarked condition for Subjects 1, 2, and 3, the incremental step-size manipulations were again identical, but treated clusters were always of a *greater* sonority value than a child's pretreatment minimal distance. Notice that, regardless of experimental assignment, all children reduced the treated cluster to its least sonorous element pretreatment. Also, with the exception of Subject 2, all children excluded the second phoneme of the treated cluster from their singleton repertoire.

The dependent variable was accuracy of production of target clusters as sampled posttreatment on the probe. Posttreatment probe responses were audio-recorded and phonetically transcribed by a trained listener using narrow notation of the IPA. Interjudge reliability of phonetic transcriptions was calculated on 26% of each of the pre- and posttreatment probe samples obtained from each child. This required a second trained listener to independently transcribe the audio-recorded samples. Transcription data from both listeners were then compared point-to-point for consonant agreement, using the formula Agreements/Agreements + Disagreements × 100. Mean point-to-point consonant transcription agreement was 90%, with the range being 87 to 94% agreement. Of the 1,518 consonants transcribed, only 6 disagreements (0.4%) were associated with cluster sequences.

Results and Discussion

Posttreatment learning data are displayed in Figure 2 for children treated in the unmarked sonority condition and in Figure 3 for those in the marked condition. The sonority difference that was actually treated is indicated by an arrow, with posttreatment production accuracy of ambient clusters plotted by sonority difference. The bars represent improvements from baseline, with hatching reflecting pretreatment performance accuracy (in the case of Subject 3). In this study, the examination of posttreatment data is most revealing of change because it reflects how treatment of a single sonority difference (and target cluster) influenced broad generalization. Posttreatment data are also ecologically valid because data obtained during treatment were indicative only of a child's production of a given target cluster in novel nonword stimuli. Of primary theoretical importance is *which* target sonority differences were acquired by the children; the specific ambient clusters that were learned are only relevant to the extent that they inform sonority difference. This directly addresses the hypothesis being tested, namely, that marked sonority differences imply all unmarked sonority differences, but not vice versa. There are secondary applied interests in the extent of improvement in ambient cluster production for purposes of potentially guiding clinical treatment.

Children enrolled in the unmarked teaching condition exhibited limited change in the production of ambient clusters following treatment, as in Figure 2. Subjects

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[2] At the point at which treatment was initiated, Subject 5 also started producing the nonambient substitute [fw] of sonority difference 4, while all ambient clusters still maintained 0% baseline accuracy. The emergence of [fw] introduced a degree of indeterminacy into this child's pretreatment minimal distance. As will be shown, however, this did not bear on the general pattern or interpretation of results associated with markedness and claims of the Sonority Sequencing Principle.

Figure 2. Posttreatment generalization learning patterns for children treated on unmarked clusters. Arrow denotes treated sonority difference. Bars reflect posttreatment accuracy of ambient clusters by sonority difference; hatching reflects pretreatment accuracy.

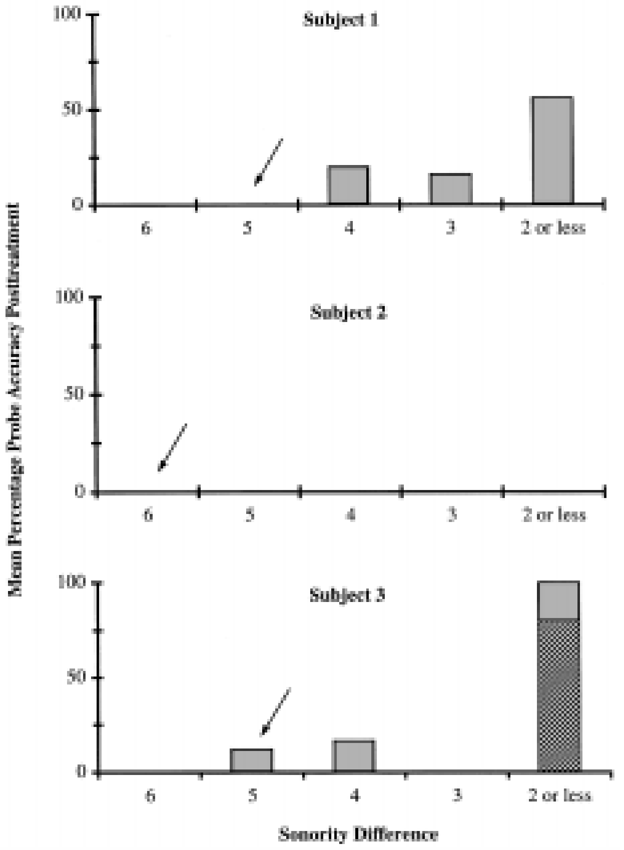
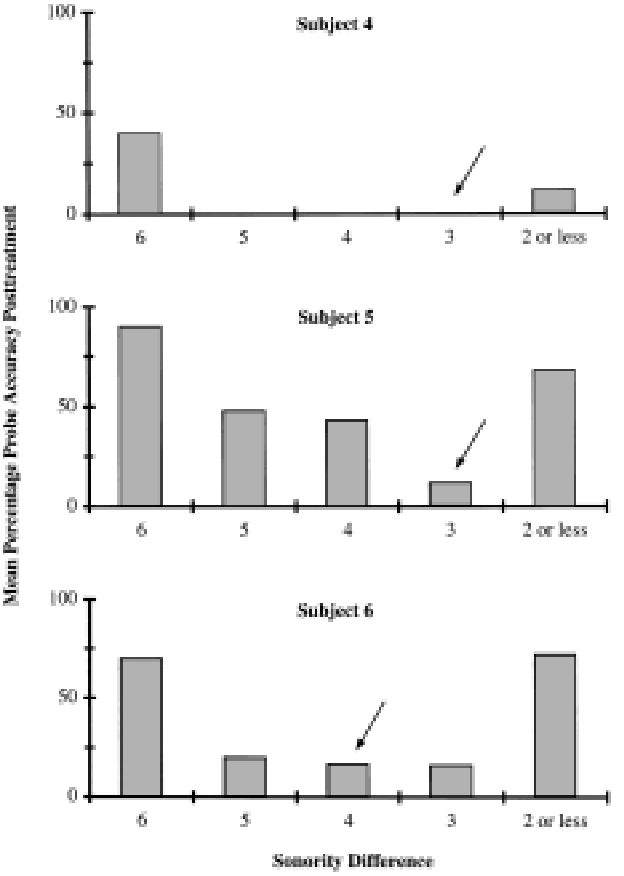


Figure 3. Posttreatment generalization learning patterns for children treated on marked clusters. Arrow denotes treated sonority difference. Bars reflect posttreatment accuracy of ambient clusters by sonority difference.



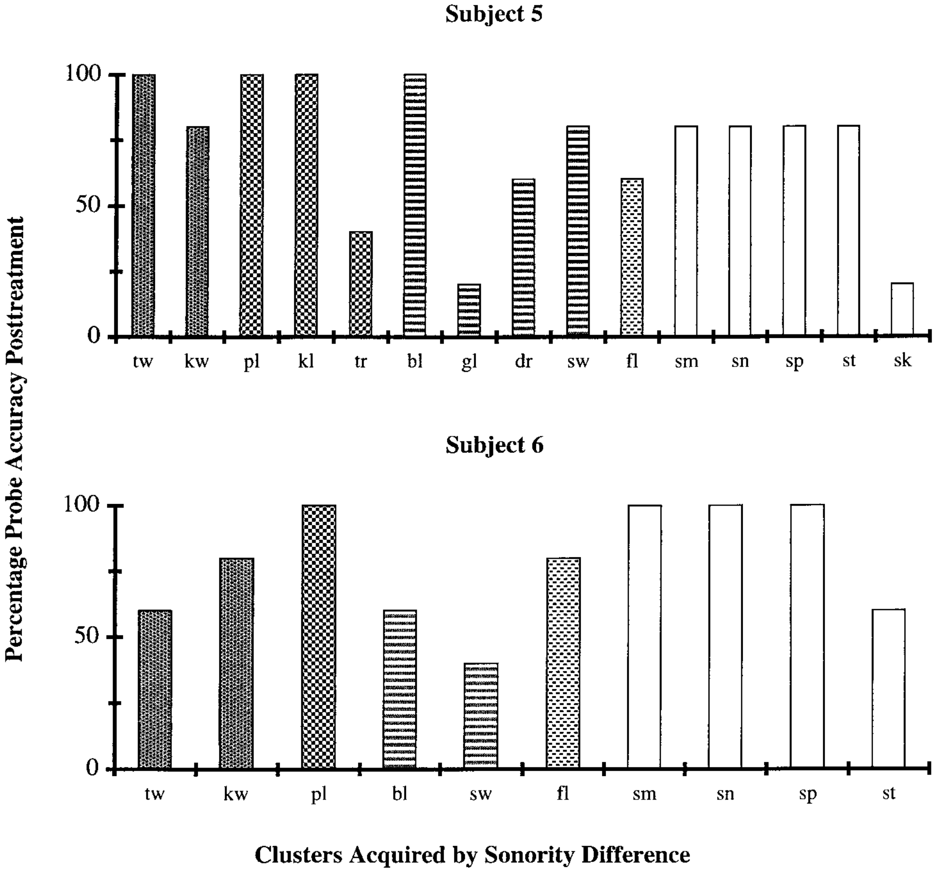
1 and 3 showed low degrees of accuracy in production, whereas Subject 2 evidenced absolutely no improvements. For the two children who exhibited change in cluster production, peak learning was observed for untreated sC clusters involving a sonority difference of 2 (or less). Interestingly, these included the presumed adjunct clusters /sp, st, sk/. All other gains were limited to instances of within-class generalization. In particular, Subject 1 acquired only the untreated clusters /bl, gl/ (sonority difference 4) and /fl, sl/ (sonority difference 3) following treatment of /kl/. Similarly, Subject 3 learned only the untreated clusters /tr, dr/ (sonority differences 5 and 4, respectively) following treatment of /pr/. Notice that neither child mastered the cluster that was taught; rather, the only clusters that were learned were related in segmental composition to the treated cluster. For Subject 1, this resulted in the emergence of certain Cl sequences, and for Subject 3, Cr sequences. Of most significance were the observed gaps in the sonority sequence such that more marked clusters occurred in the absence of other unmarked clusters. This is not predicted by the Sonority Sequencing Principle.

Subject 2's obvious lack of improvement in cluster production following the unmarked teaching condition also deserves comment. Recall that Subject 2 was the only child for whom *both* elements of the treated cluster functioned independently as singletons in the pretreatment repertoire. This child was treated on the cluster /kw/ of unmarked sonority difference 6. Moreover, /k, w/ were already part of his phonemic repertoire. Given this, it might have been thought that the acquisition of clusters (especially the treated cluster) would be facilitated. Yet, in fact, this child's phonemic use of singletons had no apparent effect on either the sequential combination of segments in the formation of clusters or the recognition that a more general Sonority Sequencing Principle is operative, even following direct intervention.

For children treated in the marked sonority condition, a different set of findings emerged, as shown in Figure 3. Five primary patterns of learning were identified, as best exemplified by Subjects 5 and 6. First, the acquisition of a marked sonority difference implied the occurrence of all unmarked sonority values. For example, Subject 5 was treated on /fl/ of the sonority difference 3 and acquired other untreated clusters of sonority differences 4, 5, and 6. Second, treatment of a marked cluster induced changes in other untreated sequences that were even *more* marked. In the case of Subject 6, treatment of the sonority difference 4 motivated change in untreated, unmarked clusters of the values 5 and 6; however, there was also further change in untreated clusters of more marked sonority differences (3 and 2). Third, a gradient pattern of learning resulted, such that the most unmarked clusters were produced with greater accuracy than more marked sequences. This was true for all sonority differences except clusters of the sonority value of 2 (or less). A fourth pattern was thus associated with a spike in mastery of these sC sequences, as was also the case in the prior teaching condition. Lastly, cluster acquisition for this group was broad and reached high degrees of accuracy. Figure 4 plots the range of clusters that Subjects 5 and 6 acquired following treatment of just one marked sequence.

At first glance, Subject 4 may appear to stand apart from other children of the marked condition; however, this child's means of acquiring clusters was wholly consistent with what has been termed a *horizontal learning strategy* (cf. Piaget, 1952, 1970; for applications, see Dinnsen et al., 1990; Dinnsen, Chin, & Elbert, 1992; Tyler & Figurski, 1994). In experimental studies of markedness that involve a series of hierarchical relationships, it has been reported that some children learn only the most unmarked element, even after exposure to a marked structure. These children master the first expected component of a markedness relationship, but do not advance through the hierarchy of relationships at the point at which treatment is terminated. A horizontal strategy of this type is not inconsistent with claims of markedness because, in fact, a child proceeds as would be expected by beginning the acquisition process with an unmarked unit. In these cases, it is thought that treatment sets the necessary foundation for subsequent learning because the linguistic principle has been appropriately induced. The data from Subject 4 seem to be in accord with this view because the process of cluster acquisition was initiated with clusters of the

Figure 4. Ambient clusters acquired posttreatment by children treated on marked clusters. Differential shadings from left to right are indicative of sonority differences 6 (shaded), 5 (hatched), 4 (striped), 3 (dotted), and 2 or less (open).



greatest unmarked sonority difference of 6. To verify a potential horizontal learning strategy, this child was monitored longitudinally. By 6 weeks posttreatment, Subject 4 had added clusters of the sonority differences 6, 5, and 4, with accurate production of /kw; pl, pr; sw/. He also exhibited high levels of accuracy in production of sC clusters of the sonority difference of 2 (or less), with use of /sm, sn, sp, st, sk/. Continuing to 10 weeks posttreatment, the child further expanded the full range of sonority types to even include clusters of sonority difference 3, producing /fr/, in addition to /br, bl, gr/. Thus, Subject 4's acquisition of clusters appeared to be generally consistent with others in the marked teaching condition. Perhaps one statement that can be made about Subject 4's learning is that treatment of modest incremental differences in markedness (i.e., a step-size of 1 in this case) may induce change less rapidly than greater step-size increments.

In summary, two distinct patterns of cluster acquisition were observed following manipulation of the Sonority Sequencing Principle. In the unmarked treatment condition, a pattern of within-class generalization learning was observed. In contrast, in the marked treatment condition, the Sonority Sequencing Principle was shown to be operative, with cluster production mirroring sonority difference in a gradient fashion. Taken together, the more marked condition appeared to be most revealing of the Sonority Sequencing Principle in phonological acquisition. This is consistent with and adds to prior observations regarding ease and breadth of learning following treatment of marked structures (for review, see Gierut, 1998b; Gierut et al., 1996). Despite these apparent differences in phonological learning associated with markedness and the Sonority Sequencing Principle, one pattern of results was consistent across conditions. Namely, there was enhanced learning of presumably the most marked clusters involving a sonority difference of 2 (or less). If these sequences were truly marked, then they should have been most difficult for children to acquire, with lower levels of accuracy expected. This leads to Experiment 2.

Experiment 2

For developing systems, there is little direct evidence to establish whether s + stop sequences are to be interpreted as unmarked adjuncts, following from violations of the Sonority Sequencing Principle, or whether they are among the most marked onsets, following from calculations of sonority difference. In contrast to fully developed systems, children's native intuitions about syllabification of true versus adjunct clusters are lacking. Moreover, the available acoustic, substitution, and metalinguistic studies involving children have often merged true with adjunct clusters in stimulus presentation, data analysis, or interpretation (Leonard & Ritterman, 1971; Menyuk, 1972; Menyuk & Klatt, 1968; Moore, Burke, & Adams, 1976; Treiman, 1985). Consequently, it is difficult to discern whether behavioral differences may be associated with true versus adjunct sequences in acquisition. Other cross-sectional descriptive studies of the age of acquisition of onset clusters have reported that s-clusters emerge relatively early in development—by about age 4 (Smit, 1993 [p. 937]; Templin, 1957). Here, again, potential differences in learning the adjuncts /sp, st, sk/ as opposed to the true s-clusters /sl, sw, sm, sn/ were not addressed, with the sC sequences being generally integrated in discussion. The results of Experiment 1, however, potentially offer a means of gaining insight into the status of adjuncts. In particular, children exhibited a learning pattern consistent with limited within-class generalization when exposed to unmarked onset structures, whereas they exhibited a gradient pattern of learning consistent with the Sonority Sequencing Principle when they were presented with marked onset structures. Given this, one hypothesis that emerges is that children's differential patterns of learning may reflect the structure of adjunct sequences. The purpose of Experiment 2 was to evaluate this hypothesis in manipulation of /sp, st, sk/ in experimental clinical treatment and to determine directly from children's learning patterns whether these sequences may be unmarked or marked in acquisition.

Method

Participants

Five children with functional phonological delays, ages 3;5 to 4;8, participated. Entry criteria were identical to those of Experiment 1 (subject characteristics are shown in Table 1). In addition, Subjects 3 and 6 of Experiment 1 served as relevant comparisons for discussion.

Phonological Analyses, Experimental Design and Treatment Procedures, and Independent and Dependent Variables

Procedures were identical to those of Experiment 1, with the exception of the experimental treatment manipulations. As shown in Table 3, three manipulations were necessary to tease apart the logical possibilities associated with the role of the adjunct. These were treatment of an adjunct versus a true cluster when no clusters were present in a child's pretreatment system; treatment of true clusters when only adjunct clusters were present pretreatment; and treatment of adjunct clusters when only true clusters were present. Each manipulation was implemented as a separate, independent,

Table 3. Experimental assignments for Experiment 2.

Subject	Pretreatment system	Treatment condition	Pretreatment minimal distance	Treated sonority difference	Treated cluster	Pretreatment substitute
6	No CC	True CC	—	4	/bl/	[b]
7	No CC	Adjunct CC	—	–2	/sp/	[b]
3	Adjunct CC only	True CC	2 (or less)	5	/pr/	[p]
8	Adjunct CC only	True CC	2 (or less)	3	/fl/	[f]
9	True CC only	Adjunct CC	4	–2	/sp/	[b]
10	True CC Only	Adjunct CC	4	–2	/st/	[t]
11	True CC Only	Adjunct CC	4	–2	/sk/	[k]

staggered multiple-baseline-across-subjects experiment.

Experiment 2A examined the learning patterns of two children who presented with no ambient or nonambient onset sequences before treatment. Subject 7 was taught the adjunct /sp/. Subject 6 from Experiment 1 served as the comparison case, having been taught a (marked) true cluster /bl/. Before treatment both children reduced the treated cluster to the least sonorous labial stop. We predicted that, if the adjunct were marked, Subject 7 would exhibit a gradient pattern of learning. Moreover, performance would be comparable to that of Subject 6, because both children would have been exposed to presumably marked sequences in treatment.

Experiment 2B introduced true cluster sequences to two children who produced target sC clusters pretreatment. Subject 8 was treated on the relatively more marked true cluster /fl/ of sonority difference 3. Subject 3 from Experiment 1 served as the replicant, having been treated on the relatively unmarked true cluster /pr/ of sonority difference 5. Again, both children reduced the treated cluster to the least sonorous element pretreatment. Regardless of the markedness value of the treated true cluster, we again expected extensive generalization learning if the adjunct were marked in status. We expected this because the acquisition process was initiated by these children with a presumably marked sonority difference given their production of the adjunct. Consequently, this alone may have triggered gradient change.

Experiment 2C presented adjunct clusters to three children who produced ambient true clusters pretreatment. Subject 9 was introduced to /sp/, Subject 10 to /st/, and Subject 11 to /sk/. As before, the children's pretreatment substitution was to the least sonorous stop. Regardless of the segmental composition of the treated cluster, we once more predicted broad patterns of change to high degrees of accuracy. If the adjunct were marked, then this treatment manipulation would have been emphasizing presumably marked structure.

Across all three manipulations, the dependent variable was posttreatment production accuracy of target clusters by sonority difference as sampled on the onset cluster probe. Mean interjudge consonant transcription reliability of these data was 92% agreement (range: 89 to 94% agreement), following procedures cited above. Of the 1,487 consonants transcribed, 12 disagreements (0.8%) were associated with cluster sequences.

Results and Discussion

Learning data are shown in Figures 5, 6, and 7. With the exception of those enrolled in Experiment 2A, all children showed some degree of accuracy in production of target clusters pretreatment—as was called for by the experimental assignments. This is denoted by the hatching in bars. The shaded portion of the bars reflects further improvements in accuracy posttreatment, with an arrow indicating the treated sonority difference.

Experiment 2A

Differential patterns of learning were observed for the children who initiated treatment with no complex onsets of any type. As in Figure 5, Subject 6 exhibited a gradient pattern of change consistent with the Sonority Sequencing Principle following treatment of the true cluster /bl/. As reported for Experiment 1, this child acquired the clusters /tw, kw; pl; bl, sw; fl; sm, sn, sp, st/, spanning the full range of sonority differences. In comparison, Subject 7 evidenced limited learning following treatment of the adjunct /sp/. This child acquired only the sC sequences /sm, sn, sp, st/, indicative of within-class generalization learning. There were also unforeseen negative consequences associated with treatment of an adjunct for this child. In particular, there was gross overgeneralization of /s/ in onset position. For all target clusters, regardless of sonority difference, Subject 7 produced /s/ as the first element of a consonantal sequence, as in [stæʔ] *quack*, [spaɪz] *prize*, [staʊd] *cloud*, and [sčut] *fruit*. This pattern persisted throughout a 2-month extended period of posttreatment follow-up. These results are consistent with the position that adjuncts may be

Figure 5. Posttreatment generalization learning patterns for Subjects 6 and 7, who evidenced no clusters pretreatment and were treated on true versus adjunct sequences, respectively. Arrow denotes treated sonority difference. Bars reflect posttreatment accuracy of ambient clusters by sonority difference.

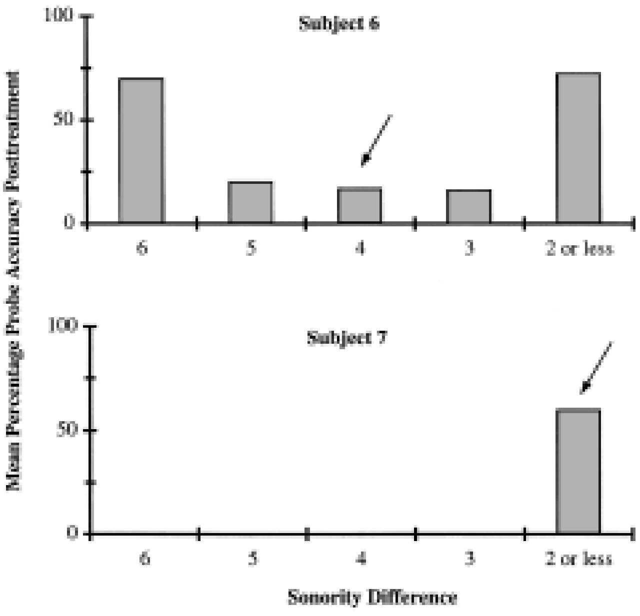


Figure 6. Posttreatment generalization learning patterns for children who evidenced sC sequences pretreatment and were treated on true clusters. Arrow denotes treated sonority difference. Bars reflect posttreatment accuracy of ambient clusters by sonority difference; hatching reflects pretreatment accuracy.

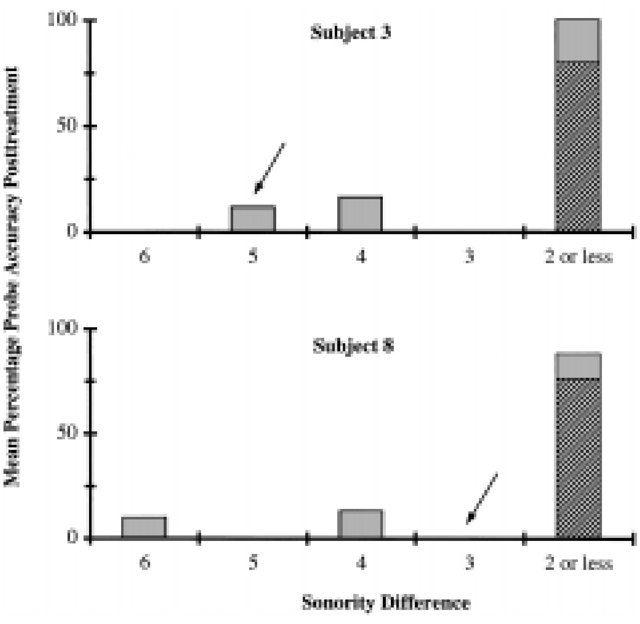
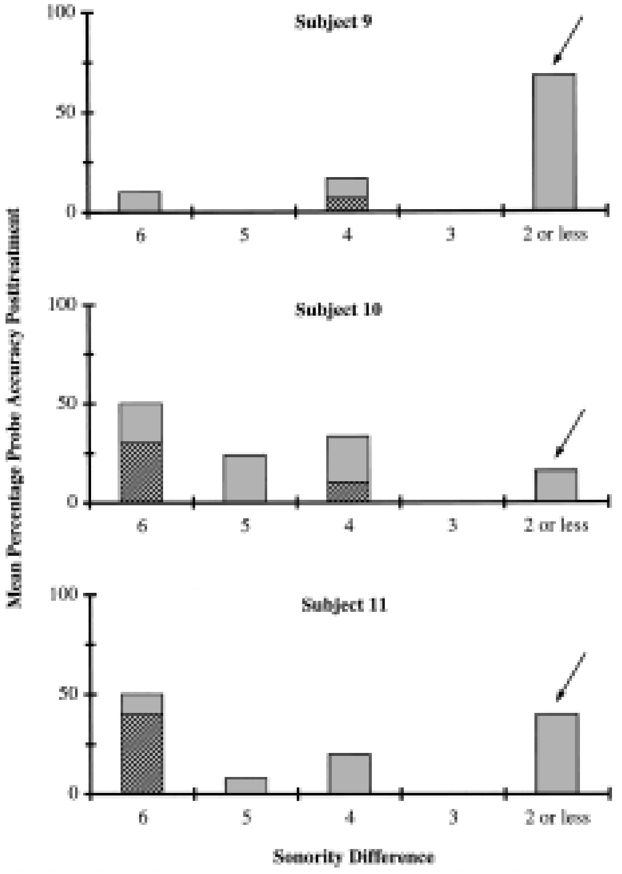


Figure 7. Posttreatment generalization learning patterns for children who evidenced true clusters pretreatment and were treated on adjunct sequences. Arrow denotes treated sonority difference. Bars reflect posttreatment accuracy of ambient clusters by sonority difference; hatching reflects pretreatment accuracy.



unmarked in acquisition. Treatment of an adjunct did not seem to be revealing of the more general Sonority Sequencing Principle, as compared to treatment of a true cluster.

Experiment 2B

The two children who produced sC sequences pretreatment were unusual in this regard alone, suggesting that these clusters may be unmarked by the very fact that they were first acquired. This was further confirmed in treatment of true clusters because the children's learning was wholly consistent with patterns of within-class generalization, as in Figure 6. Subject 3 of Experiment 1 was taught the true cluster /pr/ (sonority difference of 5) and learned only the new related clusters /tr, dr/ of sonority differences 5 and 4, respectively. Likewise, Subject 8 was exposed to the true cluster /fl/ (sonority difference of 3) but generalized only to /tw, sw/ of sonority differences 6 and 4, respectively. Neither child learned the cluster that was taught; moreover, the markedness value of the treated cluster did not seem to differentially influence learning. Cluster acquisition was limited to only those onsets that shared a common segmental element, and these were produced with less than 20% accuracy. Importantly, gaps in the implicational hierarchy were introduced because certain marked true clusters occurred in the absence of other unmarked true clusters. The data from this manipulation seem to again support the adjunct as unmarked. When acquisition began with presumably unmarked onset sequences like sC clusters, the resulting pattern of learning was restricted to within-class generalization. Treatment of a true cluster did not seem to facilitate learning in a manner consistent with the Sonority Sequencing Principle. These findings are notable because it appears that whether unmarked clusters were first induced experimentally (as in Experiment 1) or first emerged developmentally (as in Experiment 2B), the consequences for learning were the same: Unmarked clusters led to within-class generalization patterns.

Experiment 2C

For the three children of this manipulation, true clusters were present before treatment with some limited degree of accuracy. Treatment provided exposure to the adjunct, and although all children learned the treated sequence, this did not further enhance broad gradient learning (see Figure 7). As with prior manipulations, within-class generalization was observed. In particular, following treatment of /sp/, Subject 9 acquired only untreated Cw sequences /kw, sw/ of sonority differences 6 and 4, respectively. This child further exhibited overgeneralization of /s/ in onset position, as in the previous case of Subject 7. For Subject 10, treatment of /st/ prompted change only in untreated Cr sequences /pr, tr, br, dr/. For Subject 11, treatment of /sk/ motivated accurate production of untreated /tr, dr/. For all children, the extent of generalization to other untreated true clusters was limited. Observed improvements in cluster production never exceeded 25% accuracy, with gaps in the range of sonority differences that were used. Here again, the findings seem to be in accord with the adjunct as unmarked in acquisition. Even when true clusters were present in a developing system, exposure to an adjunct did not appear to give a child new insights to the full complement of sonority differences permitted in the language. Perhaps, this is because adjunct clusters maintain a sonority structure that is inherently different from true clusters.

Taken together, these manipulations converged on an unmarked status for the adjunct. The evidence for this conclusion derives from within-class generalization learning, complemented by instances of persistent overgeneralization in some cases. Consistent with and following from Experiment 1, the hypothesis that unmarked sonority differences yield within-class generalization learning was confirmed; broad gradient generalization learning associated with marked sonority differences was not observed. Despite the admittedly few subjects in each experimental manipulation, these findings appear to be robust given the systematic replication of within-class generalization effects for children who presented with no ambient clusters, only adjunct clusters, or only true clusters pretreatment. Even when children began the acquisition course in conformance with the Sonority Sequencing Principle (as in Experiments 2A and 2C), exposure to the adjunct seemed to challenge subsequent learning. A linguistic interpretation of these results may suggest that adjunct versus true clusters represents different categories given their inherent sonority structure, as is claimed for fully developed systems. A complementary developmental interpretation may also suggest that a child's existing knowledge prevents, or interferes with, new learning from occurring (cf. Farrar, Raney, & Boyer, 1992; Keil, 1989). The occurrence of overgeneralization further supported the view that /s/ is adjunct to a simple onset because children apparently (mis)understood that /s/ could be added peripherally to any target cluster.

General Discussion

The Sonority Sequencing Principle as a governing property in organization of the syllable served as the primary theoretical focus of the present investigation. We were concerned specifically with whether children obey lawful sonority relationships in their acquisition of complex onsets and whether they are sensitive to violations of these relationships in their acquisition of adjuncts.

The results of Experiment 1 demonstrated that the Sonority Sequencing Principle does function to guide children's acquisition of clusters, but seemingly only in certain circumstances. Specifically, treatment of marked sonority differences led to conformity to the Sonority Sequencing Principle. Moreover, treatment of marked aspects of the Sonority Sequencing Principle were revealing of implicationally related but unmarked and untreated structures. This finding is consistent with other studies of markedness and phonological learning in that more marked properties prompted the most extensive generalization and change (Dinnsen & Elbert, 1984; Elbert et al., 1984; Elbert & McReynolds, 1978; Gallagher & Shriner, 1975; McReynolds & Jetzke, 1986; Rockman, 1983; Tyler & Figurski, 1994; see also Gierut, 1998b; Gierut et al., 1996). In this case, children were afforded insight into the Sonority Sequencing Principle through treatment and, in fact, relied on this principle in their order and extent of mastery of production of target clusters. These data add to a growing body of evidence across language-learning populations that acquisition of superordinate linguistic structure triggers change in subordinate structure, but not necessarily the reverse (Berent & Samar, 1990; Eckman, 1991; Eckman, Bell, & Nelson, 1988; Eckman & Iverson, 1993; Haendiges, Berndt, & Mitchum, 1996; Roeper & deVilliers, 1992; Thompson & Shapiro, 1995; Thompson, Shapiro, & Roberts, 1993).

Results of the alternate unmarked treatment condition further supported this premise because not only did children of this condition exhibit less extensive change in cluster production, but the nature of change was wholly predictable from standard principles of learning. The observed patterns of within-class generalization associated with treatment of the unmarked have not been identified in prior studies of markedness. Although this may represent a novel extension, it also raises a perplexing question. Why should unmarked sonority differences have led to within-class generalization and *non*conformity to the Sonority Sequencing Principle as evidenced by gaps in sonority sequencing? The truth is that in the unmarked condition children were appropriately exposed to the Sonority Sequencing Principle, the treated clusters were legal sequences, and the order of presentation was perhaps more in line with what should have been expected in development. Yet, even when children were exposed to a full range of sonority differences, treatment that was first initiated with an unmarked cluster led to patterns of within-class learning (Gierut, 1998a).

As a possible explanation, recall that the children who participated in Experiment 1 did allow complex onsets of certain sonority differences in their pretreatment phonological systems. The permissible sonority differences were associated with *nonambient* sequences of segments, given that target clusters were not produced accurately. In the marked condition, treatment introduced a smaller sonority difference than that already allowed in a child's phonology. Additionally, this smaller sonority difference was illustrated in an ambient cluster sequence. Therefore, in the marked manipulation, the new phonological information that was being presented involved both sonority relationships and ambient sequences of segments. By comparison, in the unmarked condition, treatment was essentially aimed at a sonority difference a child already "knew," albeit incorrectly. The new phonological information being introduced was only segmental in nature given that an ambient cluster was treated. Thus, treatment of the unmarked may have drawn a child's attention to the specific segmental properties of the cluster being taught and not to anything about sonority relationships or the Sonority Sequencing Principle. Consistent with this, the resulting generalization was to other like-segments for children of this group.

This scenario is plausible when considered from contemporary constraint-based approaches to the study of language, such as optimality theory (Prince & Smolensky, 1993, 1997; Seidenberg, 1997). (See Barlow, 1997; Barlow & Dinnsen, 1998 for specific applications of optimality theory to the acquisition of onset clusters by children with phonological delays.) In contrast to derivational frameworks, where phonological rules presumably operate on underlying representations to derive surface phonetic forms, optimality theory maps relationships between the target input and a child's output through the rankings of constraints. Constraints are of two types: those that preserve a direct correspondence of features, segments, or sequences between the input and output (termed "faithfulness" constraints) and those others that define the features, segments, or sequences that are to be explicitly avoided in the output (termed "well-formedness" constraints). Constraints are thought to be universal, but their rankings vary from language to language. As generally applied to Experiment 1, the differential patterns of learning associated with the marked versus unmarked conditions may reflect a differential promotion and ranking of constraints through treatment. In the marked condition, children were apparently attuned to both the sonority and segmental properties of syllables in the input. Whereas in the unmarked condition, children concentrated only on segmental sequences. The two groups of children may have been faithful to different properties of the input when learning to change their outputs. When viewed from this general perspective, the results of Experiment 1 are not necessarily at odds with the Sonority Sequencing Principle; rather, the treatment of consonant clusters may have covertly differed across the two conditions as revealed by its effects on the ranking of constraints. For clinical application, this suggests that it may be necessary to finely direct the treatment of consonant clusters to the different phonological systems children present with. That is, the nonambient sonority differences exemplified in a child's pretreatment sound system may need to be considered when selecting ambient sonority differences for treatment. Predictably, greater learning in accord with linguistic principles of syllable structure will follow from treatment aimed at sonority differences that exceed a child's own allowable minimal distance.

This account has further implications when we turn to the results of Experiment 2 in determining the status of the adjuncts /sp, st, sk/. Converging treatment manipulations demonstrated that adjuncts may be unmarked in acquisition. This is consistent with claims from fully developed systems regarding the role of s + stop sequences, but what is unique is that learning data were invoked to disambiguate markedness status. Namely, patterns of within-class generalization were associated with unmarked structure (following further from the results of Experiment 1). When these findings are generally entertained from a constraint-based perspective, one possibility is that treatment of adjuncts may have led children down a garden path regarding the properties of syllable onsets. In particular, treatment of an unmarked adjunct would have contradicted robust sonority relationships. For those children who produced no complex onsets pretreatment (as in Experiment 2A), exposure to an adjunct would have provided "mis"information about the required sonority of syllables. For those who produced adjuncts only as in Experiment 2B (or, alternatively, true clusters only as in Experiment 2C), treatment would have set up a conflict between a child's internal grammar and universal sonority relationships. For clinical application, these results hint that adjunct sequences may need to be avoided if the goal of treatment is to promote well-formed complex onsets. Theoretically, the findings raise important questions about how adjuncts are to be reconciled in the acquisition process.

One recent proposal is that s + stop sequences may be structured like affricates in acquisition (Barlow, 1997, 1998; Lleó & Prinz, 1997; see also Barton et al., 1980; Menyuk, 1972; Selkirk, 1982). As depicted in Figure 1(d), adjuncts may be represented as complex segments with a single timing slot. A possible acquisition course that follows from this hypothesis is that children first mark syllable onsets with production of singletons, with a single timing slot, as in Figure 1(a). Then, they expand syllable onsets to include branching structure, still with only a single timing slot, as in the occurrence of complex segments—see Figure 1(d). Finally, branching onsets further expand to consist of two timing slots, with clusters of varying sonority differences ultimately being permitted in the grammar—see Figure 1(b). By this proposal, s + stop sequences would be marked relative to singletons but unmarked relative to true clusters, which is consistent with the present findings. Importantly, this proposal outlines another potential markedness relationship that may overlap and interact with the Sonority Sequencing Principle. Specifically, the occurrence of complex onsets (i.e., true clusters) implies complex segments (i.e., affricates and adjuncts), but not vice versa. This proposal offers a testable set of predictions that, if shown to be true, will establish how syllable onset structure may be formed, elaborated, and modified in the acquisition course.

Further examinations of individual differences in cluster acquisition are warranted to establish whether the proposed representational structure of adjuncts also encompasses other true sC sequences, particularly /sm, sn/. This is relevant because several of the children of this investigation regularized the sC sequences with a value of 2 (or less) in learning. For example, following treatment of an adjunct /sp, st, sk/, the children of Experiments 2A and 2C produced these sequences in addition to /sm, sn/. These same children did not necessarily produce /sl/ or /sw/. In Experiment 2B, a similar situation occurred in that children who presented with adjuncts /sp, st, sk/ extended this class to include /sm, sn/, as evidenced by additional gains in their performance posttreatment. These observations suggest that any sequence with a sonority difference of 2 may have been interpreted as a natural class. Apparently, it did not matter that the clusters /sm, sn/ appropriately rose in sonority or that /sp, st, sk/ fell in sonority. The relevant dimension seemed simply to be the shared sonority value of 2. This is further supported by the fact that /sl, sw/ of sonority differences 3 and 4, respectively, were excluded from the generalization patterns. Consequently, the natural class could not have been based solely on the commonality of the segment /s/. The question that then arises is whether adjunct clusters diverge from the true clusters /sm, sn/ in representational structure, and when and how this may take place developmentally.

Although this investigation concentrated exclusively on syllable onsets associated with clusters, the Sonority Sequencing Principle also defines the properties of acceptable codas and coda clusters. Like onsets, codas present problems for children in phonological acquisition given the frequently occurring and cross-linguistically validated pattern of final consonant deletion (Elbert & McReynolds, 1985; Leonard, 1992; Vihman, Ferguson, & Elbert, 1986). To date, the study of coda clusters in acquisition has been limited, yet one investigation of the substitution errors of children acquiring German or Spanish as the first language stands out (Lleó & Prinz, 1996). A pertinent observation that emerged from this work was an apparent relationship between complex codas and complex onsets. Evidently coda clusters emerged first in development, thereby yielding another potential implicational relationship regarding the structure of syllables. That is, the occurrence of clusters in onset position implies clusters in coda position, but not vice versa. Central issues for future research will be to determine whether the Sonority Sequencing Principle holds for order of acquisition of coda clusters and, following from markedness, whether treatment aimed at presumably more marked complex onsets will have facilitating consequences for subsequent acquisition of unmarked complex codas.

In conclusion, this investigation offered an initial perspective on the process of cluster acquisition that integrated prior accounts associated with principles of learning and principles of language. By appealing to the well-defined Sonority Sequencing Principle, it further demonstrated that sonority relationships are important governing properties of the structure of syllables in phonological acquisition, but also that these lawful relationships may be predictive of learning and change in the developmental course.

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