Syllable Onsets II: Three-Element Clusters in Phonological Treatment

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This study extends the application of the Sonority Sequencing Principle, as reported in J. A. Gierut (1999), to acquisition of word-initial 3-element clusters by children with functional phonological delays (ages in years;months: 3;4 to 6;3). The representational structure of 3-element clusters is complex and unusual because it consists of an s-adjunct plus a branching onset, which respectively violate and conform to the Sonority Sequencing Principle. Given the representational asymmetry, it is unclear how children might learn these clusters in treatment or whether such treatment may even be effective. Results of a single-subject staggered multiple-baseline experiment demonstrated that children learned the treated 3-element cluster in treatment but showed no further generalization to similar types of (asymmetric) onsets. Treatment of 3-element clusters did, however, result in widespread generalization to untreated singletons, including affricates. Moreover, there was differential generalization to untreated 2-element clusters, with individual differences being traced to the composition of children's singleton inventories. Theoretically, the results suggest a segmental–syllabic interface that holds predictive potential for determining the effectiveness and effects of clinical treatment as based on the notion of linguistic complexity.

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

The experimental evaluation of treatment efficacy involves three independent but complementary lines of study: the evaluation of treatment effectiveness, treatment effects, and treatment efficiency (Olswang, 1990). Together, these establish whether a given treatment works, the behavioral consequences of such treatment, and whether one treatment may be better than another. Recently, research on treatment efficacy has converged on a recurrent set of results, namely, greater generalization and transfer of learning may follow from treatment of more complex structures (Gierut, Eckman, & Thompson, 2000). This effect has been demonstrated across syntactic, semantic, and phonological modules of grammar. It has been documented in treatment of functional and acquired language deficits and appears to hold for children, adults, and second-language learners (e.g., Ballard & Thompson, 1999; Broselow & Finer, 1991; Eckman, Bell, & Nelson, 1988; Eckman & Iverson, 1993; Powell, Elbert, & Dinnsen, 1991; Roeper & de Villiers, 1992; Thompson & Shapiro, 1995; Thompson, Shapiro, & Roberts, 1993; Tyler & Figurski, 1994). Support for the hypothesis that complexity facilitates learning extends beyond the linguistic domain. Research in the disciplines of education (Gagné, 1968), developmental and cognitive psychology (Kit-Fong Au & Laframboise, 1990; Smith & Thelen, 1993), and philosophy (Rescher, 1998) has reported similar effects for other mental operations besides language.

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For children with functional phonological delays, the effects of complexity in treatment have been sampled for a range of experimental variables (for review, see Gierut, 1998c; Gierut, Morrisette, Hughes, & Rowland, 1996). These included manipulations of conventional clinical factors such as stimulability and developmental norms. Phonetic factors involving acoustic differentiations among sounds and inventory complexity have also been examined. Factors associated with complexity in linguistic structure have likewise been tested, including distinctive features and typological markedness. In this study, we continue the evaluation of linguistic complexity as it pertains to syllable onsets in treatment of children with functional phonological delays. The focus is on word-initial 3-element consonant clusters like /spl-/ or /skr-/.

The motivation for this research comes from several sources. First, 3-element clusters are among the most complex type of consonantal onsets permitted in English given their linguistic structure. An examination of 3-element clusters extends the notion of complexity to its uppermost limits and provides another instantiation of its role in treatment. Second, the study of 3-element clusters fills an apparent gap in the literature. To date, there have been no reports of the behavioral effects of treatment of 3-element clusters on the sound systems of children with phonological delays. Consequently, it is not known whether this form of syllabic complexity facilitates the transfer of learning. A demonstration of the effectiveness and effects of treating 3-element clusters is needed as a first step. Third, this line of study follows up recent reports on the acquisition of clusters in normal development and in treatment of phonological delays. Observations from normal development have identified a lawful relationship among clusters, affricates, and singletons that derives from structural complexity (Lleó & Prinz, 1996, 1997). Although this proposal has received descriptive support, experimental evidence is lacking. Manipulation of 3-element clusters may provide a needed validation. For children with phonological delays, differential patterns of learning have been reported in treatment of 2-element clusters (Gierut, 1999). These differential patterns were again associated with structural complexity, but of different cluster types. Treatment of 3-element clusters may replicate and extend the earlier findings by providing a unified account of the observed asymmetries.

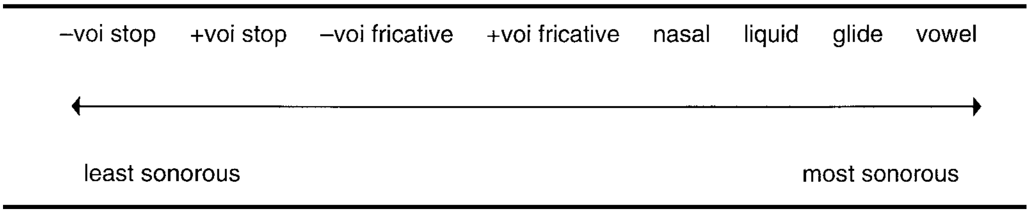
By way of background, we begin with a brief overview that draws largely from the comprehensive review we provided in our report on treatment of 2-element clusters (Gierut, 1999). The scope is limited herein to address four issues motivating the hypotheses to be tested: the linguistic structure of syllable onsets, acquisition of 3-element clusters, markedness of onsets in acquisition, and differential learning following treatment of clusters. It should be noted that there are alternative perspectives on the structure of syllable onsets and that competing theoretical interpretations about how best to model this structure have been advanced (for review see Blevins, 1995; Clements & Keyser, 1983). Additionally, there is a wealth of research on the acquisition and treatment of clusters with evidence having accrued in production, perception, acoustics, metalinguistics, and learning in first, second, and delayed language acquisition (e.g., Barton, Miller, & Macken, 1980; Eckman, 1991; Greenlee, 1974; Menyuk & Klatt, 1968; Powell & Elbert, 1984; Treiman, 1985). For a broader perspective on syllables and clusters, the reader is referred to Gierut (1999) and references therein.

Representational Structure of Onset Clusters

Linguistic theory postulates that the structure of syllables is universally governed by the Sonority Sequencing Principle (Clements, 1990). This principle states that syllables rise in sonority to the nucleus and fall or remain level in sonority to the coda. Sonority is defined by degree of aperture or loudness of sounds in a syllable (Chin, 1996) and arranges along a continuum by manner class. One such sonority hierarchy places voiceless stops at the least sonorous end of the continuum with vowels at most sonorous end as in Figure 1 (Steriade, 1990). The Sonority Sequencing Principle and the associated sonority hierarchy function to constrain the types of sounds and sound sequences (i.e., clusters) that can occur in the onset position of syllables.

Clusters in onset position are further constrained by the minimal distance in sonority that a given language allows. Minimal distance refers to the smallest permissible shift in sonority between consecutive segments in an onset. Minimal distance is crucial because

Figure 1. An expanded sonority hierarchy adapted from Steriade (1990).

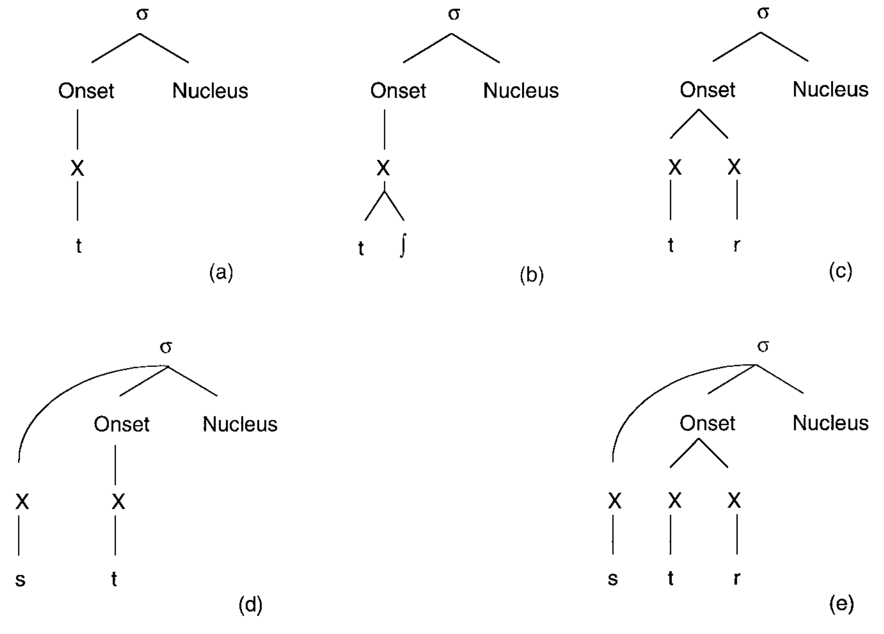


it reflects markedness: the smaller the sonority difference, the more marked the cluster (Davis, 1990, 1992; Steriade, 1990). Moreover, minimal distance establishes the full range of cluster types that are permitted in a language based on sonority. If a language allows clusters of a small sonority difference, it will also allow clusters of all greater differences but not vice versa. As with other implicational laws, only one cluster is needed at each permissible sonority difference in a given language for the lawful relationship to hold. It is not expected that all logically possible clusters must occur. Further, the segmental composition of permissible clusters will conform to the phonotactics of a particular language.

It is possible to compute shifts in sonority between consecutive segments in a cluster to determine minimal distance and markedness. This can be done most directly by counting the number of steps on the sonority hierarchy between the rankings of each of the different segments in a cluster (see Gierut, 1999, p. 710 for formal numeric calculations following from Steriade, 1990). For example, the onset cluster /kw-/ consists of a voiceless stop followed by a glide. From Figure 1, there are six sequential increases in sonority between voiceless stops and glides on the hierarchy, i.e., voiceless stop to voiced stop, voiced stop to voiceless fricative, voiceless fricative to voiced fricative, voiced fricative to nasal, nasal to liquid, and liquid to glide. /kw-/ thus has a sonority difference of 6. As another example, the cluster /sm-/ has a sonority difference of 2 since there are only two shifts in sonority between the ranking of voiceless fricatives and nasals on the hierarchy. Sonority differences such as these can then be interpreted in terms of relative markedness. Continuing the examples, the cluster /sm-/ is marked relative to /kw-/ because it has a smaller sonority difference. For English, permissible sonority differences in clusters range from 6 to 2 (by the hierarchy in Figure 1) with one possible exception.

The exception involves the s+stop clusters /sp-, st-, sk-/. These sequences violate the Sonority Sequencing Principle and minimal distance. In terms of the Sonority Sequencing Principle, the fricative /s/ is more sonorous than the following stop when it should be just the reverse. In terms of minimal distance, s+stop clusters result in a negative sonority difference (voiceless fricative followed by voiceless stop yields [–2]). Based on descriptive and behavioral evidence from languages of the world, these anomalies have resulted in a predominant view that s+stop sequences are not really onset clusters at all; rather, the fricative /s/ is thought to be adjunct to a simple onset (for evidence from English, see Giegerich, 1992; Harris, 1994; Kenstowicz, 1994; for Dutch, Fikkert, 1994; Trommelen, 1984; for Italian, Davis, 1990, 1992; for Sanskrit, Gothic, and Ancient Greek, Steriade, 1988).[1] The term "adjunct" has been used to differentiate the s+stop clusters that violate the Sonority Sequencing Principle from all other "true clusters." To better understand this linguistic perspective, we turn to the proposed representation of onsets.

Figure 2. The representational structure of (a) nonbranching singleton, (b) branching segment, (c) branching onset, (d) adjunct, and (e) adjunct+branching onset.



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[1] Some have argued that other sC sequences /sm-, sn-, sw-, sl-/ have the same representational structure as an adjunct. For discussion of this relative to normal and disordered phonological systems, see Barlow, 1997, 2001; Bernhardt & Stemberger, 1998; Gierut, 1999, p. 722.

Linguistic theory postulates that onsets of syllables may be represented in one of four ways, as simple onsets, branching segments, branching onsets, or adjuncts (for review of these and other alternatives, see Clements & Hume, 1995; Kenstowicz, 1994). These are depicted in Figure 2a through 2d; only relevant prenuclear structure is shown. The simplest type of onset to occur in language consists of only one sound associated with one timing (or consonantal) slot, as illustrated in Figure 2a for the word *two*. The one-to-one match between segmental and timing structure necessitates that the representation of simple onsets be nonbranching. Another type of onset also has a single timing slot, but it corresponds to a more complex segment such as an affricate, as in Figure 2b for the word *chew*. The affricate occupies one timing slot since it is a singleton, yet its production involves a conjunction of a stop-like followed by a fricative-like constriction. To capture this, the representation uses branching structure at the segmental level (cf. Bernhardt & Stemberger, 1998). Affricates then are branching segments. Other onsets may consist of more than one segment with more than one timing slot, as in the case of clusters. Given consistencies with and exceptions to the Sonority Sequencing Principle, it is necessary that the representation distinguish true clusters from adjuncts, as depicted in Figure 2c and 2d for the words *true* and *stew*, respectively. For the true cluster /tr-/, the singletons /t/ and /r/ each occupy a timing slot. Their function as a cluster is captured in the representation by branching structure at the level of the onset. True clusters are therefore branching onsets. In comparison, for the adjunct /st-/, there is no branching onset because /s/ is immediately dominated by the syllable node. With the exception of the appended /s/, this representation looks very much like that of a simple onset. In this way, true clusters represented with branching onsets are differentiated from adjuncts with simple onsets. Finally, given our focus, a description of the representation of 3-element clusters is in order. As in Figure 2e for the word *strew*, notice that the representation resembles that of both the adjunct and true cluster: /s/ is appended directly at the syllable level, and there is a branching onset associated with /tr-/. Three-element clusters thus combine adjunct with branching structure.

Based on typological markedness, these different representations are presumed to reflect varying degrees of linguistic complexity in onsets, with a primary determiner being branching structure. Onsets that branch are claimed to be structurally more complex than those that do not. Moreover, branching at the level of the onset is considered structurally more complex than at the level of the segment. The implication is that true clusters are more complex than affricates and that affricates are more complex than other singletons. Complexity of the adjunct as marked or unmarked in structure has not been agreed on within linguistic theory or phonological acquisition (for review see Barlow, 2001).

Acquisition of Onset Clusters

Although there have been numerous reports of children's production of onset clusters, few have examined acquisition of 3-element sequences or the emergence of clusters within a theory of syllable structure. Three sets of studies are particularly relevant in this regard. A first documents the acquisition and error patterns of 3-element clusters in cross-sectional normative reports of children acquiring English as the first language (Smit, 1993; Smit, Hand, Freilinger, Bernthal, & Bird, 1990). Typically, 3-element clusters are among the last sequences to be acquired. Within these, production of /skw-/ appears to precede other 3-element clusters. Age norms based on 75% levels of acquisition for females indicate accurate production of /skw-/ at age 4;6 (years;months), /spl-/ at 6;0, and /spr-, str-, skr-/ at 8;0 (Smit et al., 1990, p. 788). Comparable age norms for males show a slight lag, with /skw-, spl-/ produced at 7;0 and other ambient 3-element clusters at 8;0. When errors in production occur, children tend to reduce the 3-element cluster to a single sound or to another 2-element cluster, or they preserve the 3-element sequence but its segmental properties are misarticulated. Smit (1993) suggested that errors in cluster production may be treated either from a developmental perspective by targeting those singletons that comprise the cluster or a markedness perspective by targeting the cluster to facilitate production of singletons. The markedness approach was predicted to greater enhance the sound system (Smit, 1993, p. 945) and thus far has been tested in treatment manipulations of 2-element sequences (Elbert, Dinnsen, & Powell, 1984; Powell & Elbert, 1984; Williams, 1988). It has not yet been established whether treatment of 3-element clusters also facilitates singleton production; this is one goal of the present study.

A second set of studies traced the emergence of clusters relative to the representational structure of syllables in normal development for children learning German or Spanish as the first language (Lleó & Prinz, 1996, 1997; see Gierut & O'Connor, 2000, for evidence from English). The purpose was to establish whether varying degrees of representational complexity in onsets are borne out by the longitudinal course of acquisition. Indeed, the crosslinguistic results supported a gradual progression from children's production of nonbranching onsets (singletons) to branching segments (affricates) to branching onsets (true clusters). This course thus provided direct evidence of the structural complexity of onsets as proposed by linguistic theory and pinpointed specific representational prerequisites for acquisition of clusters (for a similar proposal in second language acquisition, see Archibald, 1998). Based on these results, Lleó and Prinz (1997) hypothesized that onsets may be lawfully related such that true clusters imply affricates, which imply singletons, but not vice versa. This hypothesis does not extend to adjunct sequences, nor does it bear on true clusters that may masquerade as affricates as demonstrated by their patterning (O'Connor, 2001). Nonetheless, like other proposals of typological markedness, this hypothesis is additive and implicational. The additive side resembles in many respects other maturational, learning, or attunement models of development whereby skills are gradually built upon and refined (Gottlieb, 1976a, 1976b). The implicational nature of the hypothesis, however, places it uniquely within universal theory. The reason is that such laws of language are presumed to already exist for children in full (mature adult) form as part of Universal Grammar, with input being the necessary and sufficient condition to trigger their attainment (Chomsky, 1999, p. 41; alternative dynamic systems models also rely on input to promote developmental change—see Thelen & Smith, 1994). This is intriguing for children with phonological delays because it suggests that clinical treatment may be one way to experimentally trigger the hypothesized relationship between clusters, affricates, and singletons; we examine this as a second goal of the study.

A final set of studies appealed to the representational structure of syllables in treatment of 2-element clusters for children with phonological delays (Gierut, 1999). The purpose was to determine the efficacy of teaching true clusters versus adjuncts as a potential means of establishing the markedness of adjunct sequences. Results indicated differential learning, depending on the type of cluster that was taught, with two main patterns of generalization. Following treatment of true clusters, children acquired a full range of cluster types to high levels of production accuracy. Moreover, generalization was graduated by sonority difference, with unmarked (presumably "easier") true clusters being produced with greater accuracy than those that were more marked. This pattern of learning was wholly consistent with claims of the Sonority Sequencing Principle and sonority hierarchy. By comparison, following treatment of adjuncts, children exhibited limited generalization across sonority differences with generally low levels of production accuracy and gaps in the markedness sequence. That is, clusters of marked (i.e., smaller) sonority differences occurred in the absence of other clusters of unmarked sonority differences. Gaps in markedness are not predicted by the Sonority Sequencing Principle or sonority hierarchy. Interestingly, s-adjuncts were of greatest accuracy overall despite their very small, albeit negative, sonority difference. This led to hypotheses that adjuncts may be unmarked in structure relative to true clusters and that treatment of marked true clusters may be more effective in revealing the universal characteristics of syllable onsets. Yet because 3-element clusters combine the structural properties of adjuncts and true clusters, perhaps treatment of these will jointly facilitate acquisition of both marked and unmarked sequences; this is a third goal of the study.

Thus, our purpose was to extend these proposals in a treatment manipulation of word-initial 3-element clusters for children with functional phonological delays. Three questions were addressed: (1) Is phonological learning facilitated by treatment of clusters that are among the most complex? (2) Does treatment of complex representational structure bear on other related but less complex structures such as singletons, affricates, true clusters, or adjuncts? (3) Does treatment of 3-element clusters provide a unified account of children's differential learning of clusters by drawing on common representational or phonological characteristics? Clinically, we aim to contribute to treatment efficacy by documenting the effectiveness of teaching 3-element clusters and by adding to the available evidence about the effects of linguistic complexity in treatment. Developmentally, the learning patterns to emerge may help to better isolate potential prerequisites in the acquisition of onsets. Theoretically, the findings may serve to extend our understanding of the relative complexity of different types of onset structures and the lawful relationship they may have with each other.

Methods

Participants

Eight children with functional phonological delays were recruited by public announcement to area schools, day-care and medical facilities, and community outreach programs. To be eligible to participate, children were required to score at or below the 6th percentile on the Goldman-Fristoe Test of Articulation (Goldman & Fristoe, 1986) relative to age- and gender-matched peers. They also had to display normal hearing (American Speech-Language-Hearing Association, 1985), oral motor skills (Robbins & Klee, 1987), nonverbal intelligence (Levine, 1986), and age-appropriate receptive and/or expressive language (Dunn & Dunn, 1981; Hresko, Reid, & Hammill, 1981; Newcomer & Hammill, 1988). Six males and two females were identified as potential candidates, with ages ranging from 3;4 to 6;3.

In addition to minimum entry criteria, specific characteristics were required of the children's phonological systems. In particular, children were to display a reduced consonantal inventory with a minimum of five ambient sounds excluded from the phonemic repertoire across all relevant word positions. Moreover, children were to produce only nonbranching singleton onsets.

They could not produce ambient clusters of any type in word-initial position. Quantitatively, production of target sounds excluded from the inventory and word-initial target clusters had to be 0% accurate.

To establish these specific phonological characteristics, detailed probes were administered using methods of prior studies (Gierut, 1998a; Gierut, Elbert, & Dinnsen, 1987). The probes sampled children's spontaneous productions of ambient singletons and 2- and 3-element clusters in picture-naming tasks. Targets were elicited in multiple exemplars and contexts with the potential for production of minimal pairs (e.g., *go–toe*) and morphophonemic alternations (e.g., *pig–piggie* or *hug–hugging*) as evidence of the phonemic status of sounds (cf. Dinnsen, 1984). Phonemic status of sounds was established following the criterion of two unique sets of minimal pairs, regardless of whether they were correct relative to adult production (Gierut, Simmerman, & Neumann, 1994). Probe responses were digitally recorded and phonetically transcribed by a trained listener using narrow notation of the IPA. These data were then analyzed qualitatively and quantitatively to determine the phonological characteristics needed for participation. Characteristics of children who qualified are shown in Table 1.[2]

Experimental Design and Procedures

The experimental design and associated treatment procedures were identical to Gierut (1999). A staggered multiple-baseline across-subjects design was used, with children serving as their own control. In this design, there is a baseline period followed by treatment. The number of baselines increased as successive children were enrolled, and these were blocked in such a way that three baselines were administered to the first 4 children enrolled and four baselines to the remaining children. Baseline stability was required in production of onset clusters as sampled on repeated administrations of the probes described above. All children maintained 0% accurate production of 2- and 3-element clusters over the baseline period, in addition to all of the other singletons excluded from their inventories.

Following the baseline period, treatment was provided to children on an individual basis three times weekly in 1-hour sessions. This was the independent variable. Treatment involved production of a targeted 3-element cluster presented in the word-initial position of 16 phonotactically permissible nonwords using a storytelling procedure (Gierut, 1990). Preestablished guidelines were used to develop the nonword stimuli so as to equate canonical shape, phonetic context, stress, and syntactic category (Gierut, 1999); these are described in the Appendix. Targeted clusters were assigned

Table 1. Phonological characteristics of participants.

Child	GFTA [a]	Treated CCC		Phonemic inventory and clusters [b] pre- and posttreatment	
1	–1%	skw-	Pre	m n ŋ p b t d k g f v ʧ w j h	
			Post	m n ŋ p b t d k g f v s z ʃ ʧ ʤ l w j h	kw- (6)
2	6%	skr-	Pre	m n p b t d k g f v s z ʃ w j h	
			Post	m n p b t d k g f v θ ð s z ʃ l r w j h	kw- (6); gr- sw- (4); sm- sn- (2); sp- st- (–2)
3	2%	spl-	Pre	m n p b t d f v s z ʃ r w j h	
			Post	m n p b t d g f v θ ð s z ʃ ʧ ʤ l r w j h	pl- (5); dr- (4); fl- (3); sm- sn- (2); sp- st- (–2)
4	–1%	spr-	Pre	m n p b t d k g f v ʧ l r w j h	
			Post	m n p b t d k g f v θ ð s z ʃ ʧ ʤ l r w j h	tw- (6); pr- tr- (5); br- dr- (4); fr- θr- ʃr- (3); sn- (2)
5	–1%	skw-	Pre	m n p b t d ð r w j h	
			Post	m n p b t d v θ ð z ʧ ʤ l r w j h	br- dr- (4)
6	–1%	skr-	Pre	m n p b t d w j h	
			Post	m n p b t d v ð ʧ ʤ l w j h	
7	1%	spl-	Pre	m n ŋ p b t d k g f v ð s z l w j h	
			Post	m n ŋ p b t d k g f v θ ð s z ʧ ʤ l w j h	kw- (6); bl- gl- (4); sm- sn- (2); sp- st- sk- (–2)
8	–1%	spr-	Pre	m n ŋ p b t d w j h	
			Post	Attrition	

[a] Percentile scores obtained on the Goldman-Fristoe Test of Articulation (Goldman & Fristoe, 1986).

[b] Sonority difference of clusters is shown parenthetically.

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[2] All children produced at least one ambient cluster, typically /-mp/ in coda position (cf. Selkirk, 1982, for views about the cluster status of the /-mp/ sequence). Lleó and Prinz (1996, 1997) discuss coda clusters in relation to their implicational proposal and establish these as unmarked relative to onset clusters. Two children (P1, P4) evidenced branching segments in morpheme-final position.

pseudorandomly for planned direct and systematic replications of the treatment effects. Direct replications occur when different children are taught the same target, and systematic replications occur when different children are taught different targets (McReynolds & Thompson, 1986). In this study, two children each were taught /skw-/, /skr-/, /spl-/, or /spr-/ in direct replication of treatment effects. These same clusters allowed for systematic replication within treatment of the /skC-/ series (i.e., /skw-, skr-/), the /spC-/ series (i.e., /spl-, spr-/), and the /sCr-/ series (i.e., /skr-, spr-/). The cluster /str-/ was not a potential target because the segments are all coronal, which presents special problems for interpretations of sonority (Kenstowicz, 1994), and there are no parallel /stC-/ replicants within the English language. It should noted that there was attrition of one child (P8) assigned to treatment of /spr-/ due to inconsistent attendance. To preserve the integrity of the design, this cell was not filled subsequently, but as will be shown, systematic and differential patterns of generalization resulted nonetheless.

Treatment of 3-element clusters proceeded in two phases: imitation, then spontaneous production. The imitation phase continued until a child produced the target cluster following a verbal model with 75% accuracy over 2 consecutive sessions or until 7 sessions were completed, whichever came first. Similarly, the spontaneous phase continued until a child produced the target cluster in the absence of a model with 90% accuracy over 3 consecutive sessions or until 12 sessions were completed, whichever came first.

During treatment, the child was provided feedback about production accuracy through praise and corrective modeling. The modeling procedures warrant additional description in light of the complex nature of the treatment targets. Because children did not use clusters and had reduced consonantal inventories, we anticipated that production of three consecutive consonants in sequence might require special support in the form of graded feedback. Yet because the treatment goal was to elaborate onset structure, we did not want to emphasize specific sounds. Corrective modeling could not be tailored to a given child's errored outputs, because then treatment would not be standardized. To accommodate these concerns, corrective modeling was specific to each trial, with an average of seven trials per session. If errors were produced in the first trial of a session, then the model to follow emphasized sequencing the full 3-element cluster, e.g., [sprɛnɑ]. If errors occurred in the next two trials, then the model was graded with emphasis on sequencing the first two sounds of the 3-element cluster, e.g., [spə rɛnɑ]. In the next two trials, modeling was again graded, but now to emphasize the last two sounds of the 3-element cluster, e.g., [s prɛnɑ]. Graded modeling continued to alternate by trials of two within a session and was counterbalanced across sessions. To close out every session, the corrective model again emphasized the complete 3-element sequence in the final trial. This modeling procedure was kept in place just until a child was able to produce three consecutive consonants in onset position regardless of accuracy. This generally took the full seven sessions of the imitation phase. In remaining sessions, feedback was delivered only by modeling the complete 3-element cluster as in the first and last trials above. This procedure ensured that children systematically received the same kind of graded input about complex onsets regardless of the specific nature of their errors. The procedure focused equally on different aspects of 3-element sequences so as not to inadvertently draw attention to or place undue emphasis on one kind of representational structure as opposed to another. If we were to find that children learned in different ways following exposure to the same modeling procedures, then learning would need to be traced to variables other than the feedback provided in treatment.

Two dependent variables were measured: learning during treatment and generalization from treatment of 3-element clusters. Learning during treatment was operationalized as the percentage accuracy of production of 3-element clusters in nonword stimuli. Production accuracy was judged by the clinician (AHC) trial-by-trial in day-to-day treatment. Generalization from treatment was operationalized as the percentage accuracy of production of real words as sampled on the picture-naming probes described above. For each child, accuracy of production of all target 2- and 3-element onset clusters was measured, in addition to accuracy of production of singletons excluded from the pretreatment inventory. Generalization probe data were digitally recorded and subsequently transcribed by a trained listener using narrow notation of the IPA to derive the percentages of accuracy. Reliability of these transcriptions was computed by having an independent listener also transcribe a subset (27%) of the probe data. Consonant transcriptions were compared point-to-point since these were the data used to establish learning and generalization; vowels and diacritics were set aside. Mean interjudge agreement was 93% (range = 91–96% with 1,742 consonants transcribed). Of the consonants transcribed, only 0.8% of the disagreements related to onset clusters.

Results and Discussion

The results of teaching word-initial 3-element clusters to children with functional phonological delays are discussed in terms of learning during treatment and generalization from treatment. Learning during treatment is relevant to establishing treatment effectiveness;

namely, does treatment of 3-element clusters work? Generalization from treatment is perhaps of more importance because this reflects the overall effects of such treatment as internalized in a child's phonology. Together, these complementary perspectives are used to evaluate hypotheses about complexity in the representational structure of onsets from applied clinical and theoretical linguistic perspectives.

Learning During Treatment

Learning curves for each child are displayed in Figure 3. Accuracy in production of the treated 3-element cluster is plotted longitudinally during baseline, imitation, and spontaneous phases of treatment. From these data, it can be seen that all children increased production accuracy from 0% baseline levels, despite individual differences in the slopes of the learning curves. On average, children responded with 52% accuracy at completion of the imitation phase. When treatment shifted to the spontaneous phase, production accuracy temporarily declined for some children, as might be expected in the transition from support of a verbal model to no such model. As the spontaneous phase continued, production accuracy reached 83% to 92% for all children. These gains were observed over an average of 19 sessions (range = 16–19).

It is noteworthy that treatment of 3-element clusters resulted in similar learning patterns across children regardless of the specific cluster being taught. The segmental composition of the treated cluster did not seem to differentially affect children's learning, even though certain sound sequences may have appeared to be more challenging (e.g., 3-element clusters consisting of developmentally later acquired /r/). This similarity in learning may have been associated instead with the representational structure commonly shared by the treated 3-element clusters (Figure 2e). Treatment may have drawn children's attention to the structure of complex onsets, as we had intended, rather than to individual segments. One clinical implication is that, in selection of treatment targets, a given 3-element cluster may be just as appropriate as any other in inducing productive change; we return to this later in the Discussion section.

Generalization From Treatment

Generalization is reported for treated and untreated 3-element clusters, untreated 2-element true clusters and adjuncts, and untreated singletons as a reflection of overall change in children's grammars. Generalization data are reported as percentages of accuracy in production as measured on posttreatment phonological probes in Figures 3 through 5. The relevant comparison is between 0% pretreatment and posttreatment probe performance.

Three-Element Clusters

Posttreatment production of 3-element clusters is shown in Figure 3 for all children. An immediate observation is that children evidenced little or no transfer of learning to 3-element clusters, whether treated or untreated. Despite improvements in production during treatment, there was a return to baseline following treatment.[3] This is significant experimentally and clinically. Experimentally, a return to baseline within single-subject designs is an explicit demonstration of the causal relationship between treatment and learning and is taken to be truly indicative of a treatment's effectiveness (McReynolds & Thompson, 1986, pp. 198–200). The premise is that a behavior will remain stable until the instatement of treatment and only then will there be a (desired) change in performance. To establish that treatment (and not some other extraneous or maturational factor) is responsible for the change in behavior, baseline levels of performance are expected to resume when treatment is withdrawn or discontinued. By this logic, a return to baseline in this study signaled that improvements in production of 3-element clusters were a direct consequence of treatment itself. Clinically, however, a return to baseline is a less than ideal outcome. Children's lack of generalization may have come about for at least three reasons. One possibility is that treatment involved nonwords, whereas generalization probes sampled real words. Perhaps transfer from nonword to real-word stimuli was hindered. Though plausible, this does not seem likely given numerous other studies that have reported extensive phonological generalization following nonword treatment (see Gierut, 1998c, for review). Another possibility is that 3-element clusters were simply too difficult. This does not seem likely, because children were able to learn 3-element clusters during treatment itself. A final possibility, and the one we pursue, is related to linguistic complexity and its effect on phonological learning. Consider that a lack of generalization to 3-element clusters suggests only that treatment did not trigger change in that very same type of representational structure, namely adjunct+branching onsets. Yet, because linguistic theory postulates that onset structure lies on a continuum of complexity, it is possible that other implicationally related but less complex structures may have generalized. This would be consistent with other clinical applications of markedness whereby treatment of marked phonological structures promoted change in unmarked structures (e.g., Dinnsen & Elbert, 1984; Elbert et al., 1984; Elbert & McReynolds, 1978; McReynolds & Jetzke, 1986; Tyler & Figurski, 1994). In this study, even though treatment

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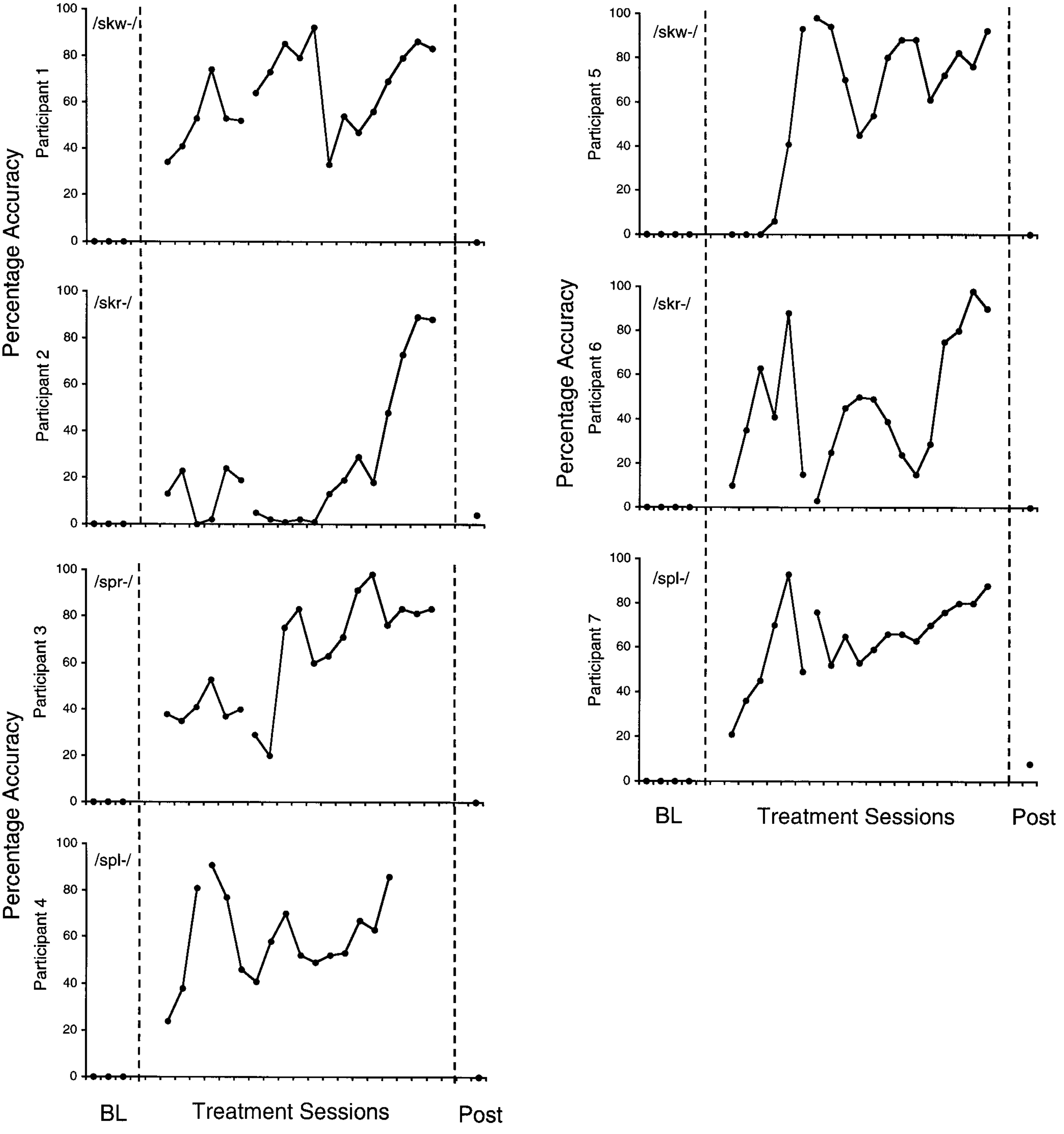
[3] Generalization accuracy of 2% and 8% for P2 and P7, respectively, is within the ±10% baseline variation that is conventionally allowed in single-subject designs.

Figure 3. Production accuracy of 3-element clusters during baseline, treatment sessions, and posttreatment. Performance during the imitation, then spontaneous, phase of treatment is noted by a break in the learning curve.

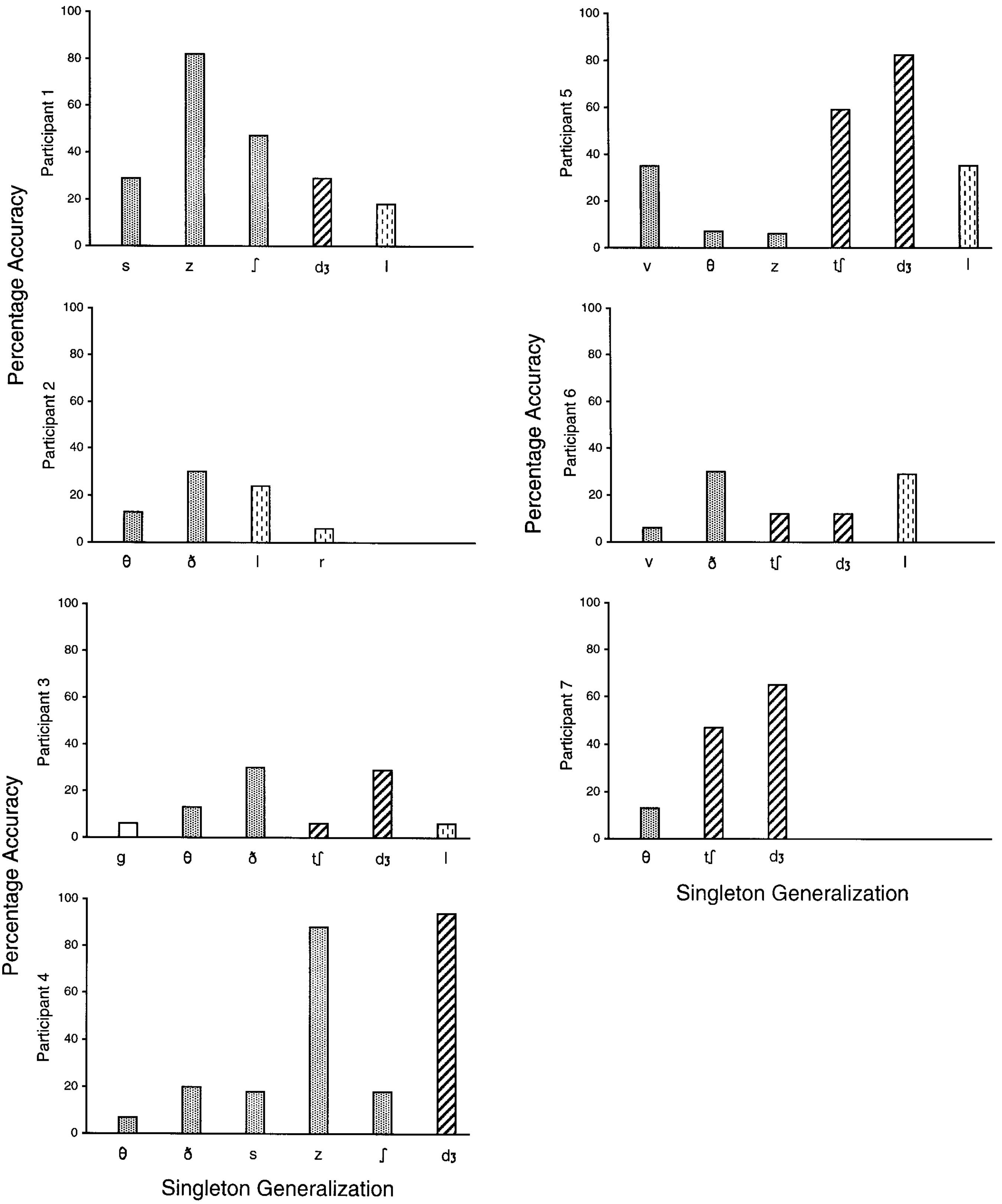


did not induce generalization to like 3-element clusters, it may have triggered broader changes in other unmarked onsets, including singletons, affricates, and 2-element clusters, as predicted by both Lleó and Prinz (1996, 1997) and Smit (1993).

Singletons and Affricates

Target sounds excluded from children's pretreatment inventories were evaluated posttreatment with respect to expansion of the singleton repertoire. Figure 4 plots quantitative gains in accuracy of production of

Figure 4. Posttreatment production accuracy of untreated singletons by manner class: stops (open), fricatives (shade), affricates (hatch), and liquids (dash).



these sounds relative to 0% baseline; Table 1 provides a summary of sounds added to each child's inventory following treatment.

Children substantially increased the size of their singleton inventory following treatment of 3-element clusters. On average, five untreated sounds were added to the repertoire (range = 3 to 6). Production accuracy of untreated sounds ranged from 6% to 94%, with average performance being 30%. As before, the 3-element cluster that was treated did not appear to differentially affect children's generalization to singletons. Singletons acquired were not necessarily subsets of treated 3-element clusters. For example, /s/ was the first segment of each treated cluster, yet some children added /s/ to the posttreatment inventory, whereas others did not (e.g., P1, P4 vs. P5, P6, respectively). This was true across children for other untreated stop or liquid subsets of treated 3-element clusters.

Certain other segmental changes in the composition of children's inventories warrant mention. Recall that linguistic theory makes a distinction between singletons with nonbranching as compared to branching structure. Affricates are branching segments, whereas other singletons are nonbranching (Figure 2a, 2b). Nonbranching onsets are thought to be unmarked relative to branching segments, which in turn are unmarked relative to branching onsets. This claim was borne out in part by children's generalization to singletons. Table 1 shows that five children (P2, P3, P5, P6, P7) did not evidence affricates before treatment of 3-element clusters. Their productive knowledge of syllable onsets was limited to only simple segments with nonbranching structure. By the completion of treatment, 4 of the 5 were accurately producing untreated affricates. The one child (P2) who did not produce affricates target-appropriately did add nonambient affricates /ts, dz/ to the posttreatment system, as evidenced by the use of minimal pairs. In essence, all five children conformed to the predicted course of acquiring singletons, then affricates. Of significance is the fact that this occurred following treatment of adjunct+branching structure in the form of 3-element clusters.

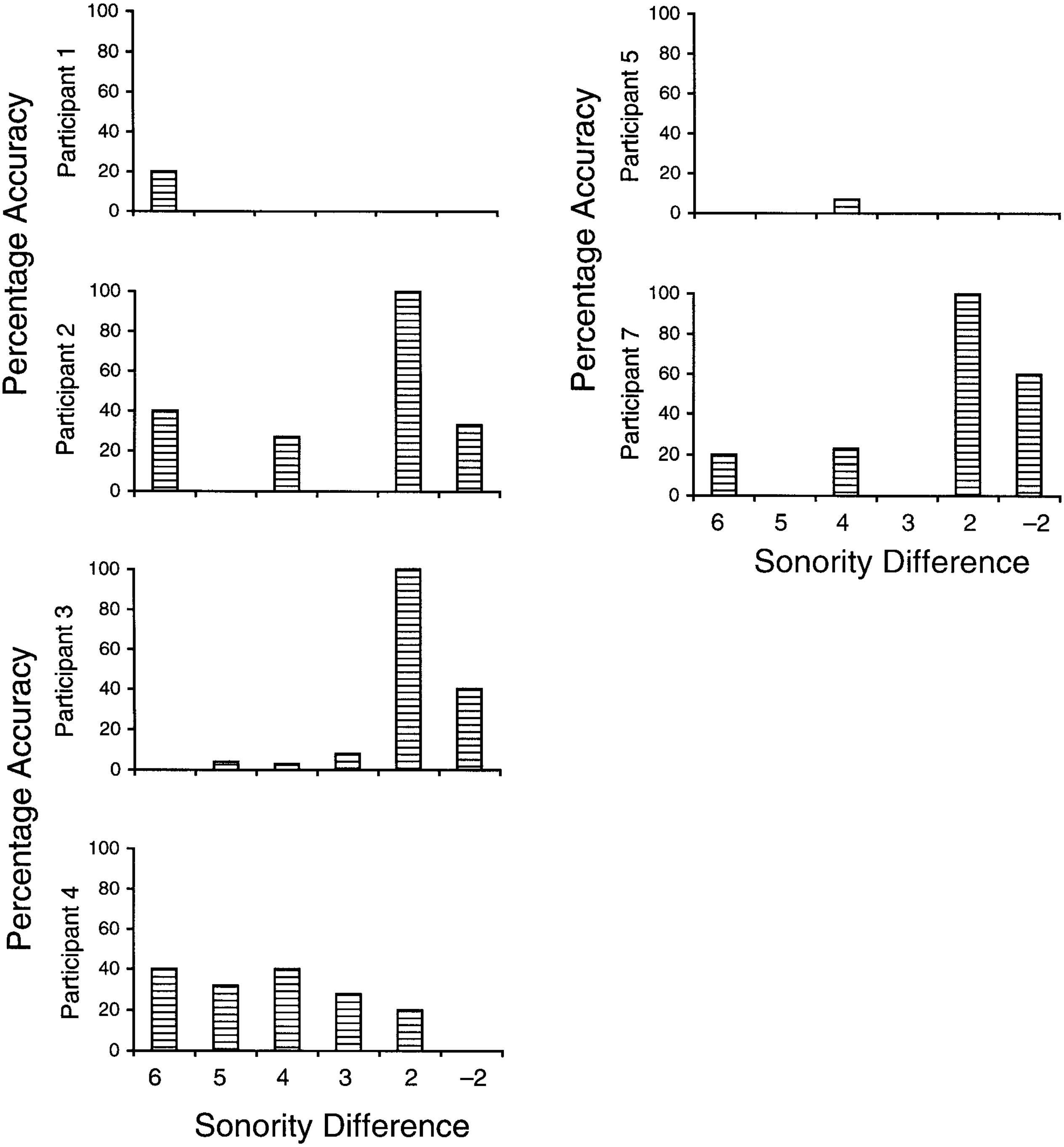
There were also other singletons commonly added to children's inventories, including the liquid /l/ and the interdental fricatives /θ, ð/. These specific sounds would not necessarily be predicted by hypotheses about representational complexity because these are simple segments with nonbranching onsets. Their emergence would not violate the proposal either because singletons are included as part of the implicational relationship. Perhaps there were additional lawful relationships operating in concert to further guide children's expansion of the repertoire of nonbranching onsets. For instance, there are known relationships among featural distinctions that govern the complexity of phonetic as well as phonemic inventories (Dinnsen, Chin, Elbert, & Powell, 1990; Gierut et al., 1994; Rice & Avery, 1993, 1995). There are also other established relationships among manner classes of sounds and word positions (Ferguson, 1977; Greenberg, 1978; Smith, 1973). These laws are implicational, but at the featural or segmental level of structure as opposed to the syllabic level we are considering here. It would be beyond the scope of this paper to speculate how featural, segmental, and syllabic markedness may interact, but this is a topic that has recently been garnering attention within Optimality Theory (Prince & Smolensky, 1993; in acquisition, see Bernhardt & Stemberger, 1998).

Two-Element Clusters

Posttreatment generalization to 2-element clusters is presented in Figure 5 for all children. The data are displayed by sonority difference, with a difference of 6 being least marked, 2 being most marked, and –2 being the adjunct. Recall that by the Sonority Sequencing Principle and sonority hierarchy, the smaller the sonority difference, the more marked the cluster. Further, the occurrence of a marked sonority difference necessarily implies all other unmarked differences.

Three patterns of generalization to 2-element clusters were observed. A first pattern was characterized by generalization to true clusters consistent with the Sonority Sequencing Principle and markedness. This was exhibited by 2 children, P1 and P4. To illustrate, P4 learned untreated true clusters representative of the full range of sonority differences of English following treatment of /spr-/. He learned marked and unmarked sequences with no gaps in the range of sonority differences allowed. The presence of true clusters of a small sonority difference of 2 implied all greater values 3, 4, 5, and 6. P1 presented a similar, albeit limited pattern of change in untreated true clusters. This case was also consistent with the Sonority Sequencing Principle because unmarked clusters of sonority difference 6 were first acquired. Notably, the results from these two children directly paralleled Gierut's (1999) earlier findings, whereby treatment of 2-element true clusters promoted learning in conformity with the Sonority Sequencing Principle and markedness. Perhaps this subgroup of children focused their attention on the branching portion of adjunct+branching onsets in treatment. This would be compatible with the structure of untreated 2-element true clusters that the children actually learned. It is of further significance that this subgroup used affricates in the pretreatment inventory. Their resulting generalization pattern was consistent with Lleó and Prinz's (1997) predicted course of onset elaboration, beginning with singletons and branching segments,

Figure 5. Posttreatment production accuracy of untreated 2-element clusters plotted by sonority difference.



then advancing to branching onsets associated with true clusters.

A second pattern of generalization was characterized by the acquisition of adjuncts with associated violations of the Sonority Sequencing Principle and markedness. Three children presented this type of change: P2, P3, and P7. To illustrate, P7 generalized to the adjuncts /sp-, st-, sk-/ following treatment of /spl-/. In addition, he acquired other true clusters of sonority differences 6, 4, and 2; however, there were gaps in the markedness sequence. Marked sonority differences did not imply all other unmarked differences, which challenges linguistic claims. P2 and P3 exhibited comparable sorts of change. As before, these results resembled Gierut's (1999) prior findings following treatment of 2-element adjuncts. Previously, treatment of adjuncts was thought to predispose a child to form erroneous hypotheses about syllable structure. Because adjuncts violate the Sonority Sequencing Principle, treatment of an adjunct provides a child with input that does not conform to the universal structure of syllables. This potentially leads to errored conclusions about how syllables are to be structured, hence the observed markedness violations (see Gierut, 1999, pp. 721–722, for further details). Perhaps this subgroup of children from the present study attended to the adjunct portion of the representational structure of adjunct+branching onsets in treatment. Although these children did learn some true clusters associated with branching onsets, their initial emphasis on the adjunct may have led them astray, yielding gaps in generalization.

A final pattern of generalization involved virtually no change in 2-element sequences as exhibited by P5 and P6. P6 demonstrated no generalization, whereas P5 generalized only modestly to clusters of sonority difference 4.

Interestingly, differential patterns of learning were only associated with generalization to 2-element clusters. Individual differences were not observed during nonword treatment or in generalization to untreated singletons, affricates, or 3-element clusters. Differential patterns emerged despite the fact that all children were exposed to the same kind of onset structure and corrective feedback in treatment. This suggests that children may have parsed adjunct+branching onsets in unique ways given their differential learning. A critical question is why this might have occurred.

Table 2 displays a range of factors potentially predictive of differential learning of 2-element clusters. Age did not appear to be relevant. Younger children learned more than older children and vice versa. For example, P1 (chronological age [CA] 5;6) and P2 (CA 3;4) both generalized as compared to P6 (CA 4;0), who did not. Treatment target was also not informative. Children exposed to the same target cluster learned in different ways. To illustrate, P2 and P6 were both treated on /skr-/, but generalized to adjunct and no clusters, respectively. Children's substitutions were examined, but these did not hold as a viable explanation of the differences either. For instance, P4 and P7 both substituted labial stops for 3-element clusters, but generalized to true clusters and adjuncts, respectively.

There was only one factor that surfaced as potentially contributing to differential learning, that being the segmental composition of children's pretreatment phonemic inventories. Sounds that children used phonemically were wholly predictive of generalization to 2-element clusters. To demonstrate, consider that each sound of the treated 3-element cluster, Consonant 1, Consonant 2, and/or Consonant 3, may have been used by a child as a contrastive singleton. In this study, if the pretreatment phonemic inventory consisted of C1 and C2 as singletons, then generalization was to adjuncts as for P2, P3, and P7. Notice that C1 and C2 directly map onto that portion of the representational structure of treated 3-element clusters that would promote /s/ as an adjunct (Figure 2e). Similarly, if the pretreatment inventory consisted of C2 and C3 as singletons, then generalization extended to true clusters as for P1 and P4. Here, C2 and C3 corresponded to the branching onset portion of the representational structure of treated 3-element clusters. Finally, if the pretreatment inventory consisted of just one (or no) singleton of the 3-element sequence, then no generalization to 2-element sequences was observed as for P5 and P6. We might also have expected the latter type of generalization for P8 (who resigned from the study) given the composition of his phonemic inventory. Thus, the singleton inventory relative to the treated cluster appeared to predict subsequent generalization to 2-element sequences for these children.

There are two additional factors related to the singleton inventory that may have contributed to differential generalization, but, independently, these could not fully account for the data. One factor was size of the inventory, specifically as it pertained to P5 and P6. Neither of these children exhibited generalization, and both had severely reduced inventories. A small inventory size may

Table 2. Potential predictive variables of differential generalization.

Child	Pattern of differential generalization	Age	Treated CCC	Substitution for the treated CCC	Phonemic overlap with treated CCC	Phonemes excluded	Affricate
1	True CC	5;6	skw-	Coronal stop	C2 C3	8	Yes
2	Adjunct with gaps	3;4	skr-	Coronal stop or fricative	C1 C2	7	No
3	Adjunct with gaps	4;10	spl-	Labial fricative	C1 C2	8	No
4	True CC	5;3	spr-	Labial stop	C2 C3	7	Yes
5	Little to no generalization	4;2	skw-	Coronal stop or labial glide	C3	12	No
6	Little to no generalization	4;0	skr-	Coronal stop	None	14	No
7	Adjunct with gaps	6;3	spl-	Labial stop	C1 C2 C3	5	No
8	Attrition	5;10	spr-	Labial stop	C2	13	No

have hindered these children's ability to generalize. Yet if size were truly relevant, then children with the same inventory size might be expected to learn in comparable ways. This was not the case, as best exemplified by P1 and P3, who both excluded eight phonemes but generalized to true clusters and adjuncts, respectively. A second factor was presence of affricates in the inventory as related to P1 and P4. These children generalized to true clusters, presumably by elaborating on their pretreatment knowledge of the structure of affricates and singletons. The fact that these children were consistent with predictions about the emergence of complex onset structure may have facilitated their generalization. However, if affricates were critical, then other children who did not use affricates might also be expected to learn in the same fashion. Again, the results demonstrated that this did not obtain because children without affricates presented two unique patterns of generalization. Although inventory size and affricates may have played some role in generalization to 2-element clusters, neither was a necessary and sufficient condition. Segmental composition thus was the sole variable that afforded a unified account of children's differential learning of 2-element clusters.

General Discussion

The goal of this study was to document acquisition of word-initial 3-element clusters by children with functional phonological delays. This study served as a further evaluation of the emergence of complexity in onset structure and of the Sonority Sequencing Principle relative to treatment efficacy. Overall, learning and generalization took place following treatment of 3-element clusters with well-defined cases of individual variability. The patterns common to all children included broad expansion of untreated singletons, acquisition of untreated affricates, and no transfer of learning to treated or untreated 3-element clusters. Individual differences were limited to generalization of 2-element clusters, with differential patterns of learning being traced to children's singleton inventories. Sounds in the pretreatment inventory predicted the type of 2-element clusters that would be learned.

In large part, these findings were consistent with and extended prior studies of cluster acquisition in normal and delayed phonological development as framed within a linguistic perspective on syllable structure. With regard to normal development, all children of this study generalized in accordance with the prediction of Lleó and Prinz (1996, 1997) that elaboration of syllable onsets will begin with simple nonbranching structures (as for P5, P6), and then will extend to affricates as branching segments (P2, P3, P7) followed by true clusters with branching onsets (P1, P4). These treatment data complement their longitudinal crosslinguistic research and support potential implicational relationships in onset complexity. As predicted for normal acquisition, these relationships may be interpreted as phonological prerequisites to more complex onset structure. Importantly, however, this study showed that treatment of complex structure involving adjunct+branching onsets triggered changes in other less complex but implicationally related prerequisites. This is compatible with hypotheses about the general effects of markedness on learning and provides another instantiation of linguistic complexity in clinical treatment.

With regard to phonological delays, treatment of 3-element clusters replicated the patterns of change previously reported by Gierut (1999) following treatment of 2-element clusters, with one unique extension. That was the predictability of change in clusters as derived from the singleton inventory. Theoretically, this implies that what children may know about simple nonbranching onsets will predispose them to what can later be acquired about more complex representational structures. Children of this study apparently evaluated the structural and segmental characteristics of onsets in parallel, as the type of structures they learned were constrained by the segments they knew. This is not to say that children simply mapped known segments onto new representational structures. The 2-element clusters that were learned were not just combinatorial permutations of known segments; rather, children were discriminating in cluster generalization. During treatment, they must have first examined known sounds in the context of new onset representations. Then depending on how these sounds overlapped with new onset structure, they extended this correspondence to other like structures. This is consistent with proposals about the elaboration of linguistic complexity in acquisition (Rice & Avery, 1993, 1995; Slobin, 1971), but in this case, the association was between segmental and syllabic levels of representation. Moreover, this relationship between segments and syllables had to have been inferred by the children because their input in treatment was a 3-element cluster, although their associations in generalization were between singletons and 2-element clusters. This stands apart from other treatment recommendations and protocols that have relied on known patterns of production as a base for new productions, but through explicit and direct instruction (e.g., Bernhardt & Stemberger, 2000; Gierut, 1989; Weston & Irwin, 1971; for an evaluation of the efficacy of this treatment approach, see Gierut, 1992).

A segmental–syllabic interface of this type has potential clinical implications. In terms of diagnostic considerations, a child's singleton inventory and the sounds that are used contrastively as phonemes appear to be central to establishing clinical goals related to treatment of 3-element clusters. In contrast to studies that have focused on descriptions of children's substitutions for clusters (e.g., Chin & Dinnsen, 1992; Smit, 1993), these results suggest instead that a diagnostic characterization should identify those singletons used independently of clusters. This represents a shift in focus from phonemes that are absent from the inventory to those that are present in a child's sound system. An independent approach to analysis may better facilitate the selection of a target cluster for treatment and the prediction of subsequent generalization learning.

In selection of a treatment target, a further implication is that certain 3-element clusters may be favored over others simply given the composition of a child's singleton inventory. In determining which 3-element cluster may be most appropriate to teach, a number of recommendations arise from the results of this study. A first is that a child's singleton inventory should include a subset of the consonants of the 3-element cluster to be treated for best results. If the inventory subset includes C2 and C3 of the targeted cluster, then this may be a preferred starting point of treatment for 3-element clusters. Based on the present findings, it is likely that broad generalization to singletons, affricates, and true clusters will occur. In addition, generalization is expected to be consistent with universals of syllable structure, including the Sonority Sequencing Principle and sonority hierarchy. Predictably, treatment of 3-element clusters will provide such a child with relevant input about the lawful and prerequisite relationships among syllable onset structures. If the singleton inventory includes instead C1 and C2, then treatment of 3-element clusters is again likely to promote singleton expansion with production of untreated affricates. However, generalization to 2-element sequences may be asymmetric relative to the onset structure of syllables. A child might predictably learn adjuncts, but the occurrence of other true clusters may be sporadic. In this case, treatment of 3-element clusters may prompt a child to form erroneous hypotheses about onset structure, similar to what was suggested previously in treatment of 2-element adjuncts (Gierut, 1999, pp. 721–722). It remains for future research to determine if the predicted singleton gains will sufficiently outweigh potentially adverse consequences for the acquisition of complex onset structure. Finally, if the singleton inventory is severely restricted, consisting of one or fewer members of a target 3-element cluster, then treatment of 3-element clusters may also need to be carefully considered. For phonological systems such as these, it is likely that there will be generalization to singletons, including affricates, with little or no generalization to other types of complex onsets. Because of the expected lack of generalization, it is not clear whether children will form hypotheses consistent with or in violation of the Sonority Sequencing Principle and markedness during treatment of 3-element clusters. Continued longitudinal documentation of learning may help to further resolve the ambiguity in these cases. It must also be underscored that these predictions bear only on the selection of 3-element clusters as potential treatment targets.

All in all, these clinical recommendations hint that some children may be better suited for treatment of 3-element clusters than others on the basis of the composition of their singleton inventories alone. This is a first demonstration that linguistic complexity in treatment may be constrained in specific ways by a child's presenting phonological system. The findings and recommendations are, of course, preliminary and require replication and validation in subsequent studies involving children with alternate phonological profiles. There are at least three logically possible singleton subsets of 3-element clusters that remain indeterminate relative to observed differential generalization patterns. One is the occurrence of all three members of a treated cluster, C1, C2, and C3, in the singleton repertoire. In this study, P7 presented such a case. This child generalized consistently with the adjunct and associated markedness violations, thereby emphasizing C1 and C2 of the treated cluster. Yet it was just as likely that P7 could have generalized in accordance with true clusters by focusing on C2 and C3 instead. It will be necessary to monitor generalization patterns of other children with these singleton characteristics in order to discern the expected course of learning and to identify potential factors that may promote a given pattern over another. A second possibility involves the occurrence of C1 and C3 as singletons to the exclusion of C2. None of the children of this study exhibited this segmental subset, but it may be uncommon (Dinnsen et al., 1990; Gierut et al., 1994). The reason is that C2 is the least sonorous segment of a 3-element cluster, that being a stop /p, t, k/. That a child's inventory would include fricatives and liquids (C1 and C3, respectively) to the exclusion of at least one stop consonant seems a less likely occurrence. This notwithstanding, if observed, this segmental profile should also be evaluated in terms of differential generalization. A third possibility involves the occurrence of either C1 or C2 alone as singletons. None of the children who completed treatment in this study exhibited this singleton subset. However, it might be thought that C1 in the repertoire would predispose a child to the adjunct, but that C2 would predispose a child to the true cluster. This projection derives from the way in which these singletons partially map onto the representational structure of 3-element clusters. Further study of children who have highly restricted singleton inventories is warranted to fully establish the effects of treatment of 3-element clusters.

Future research also calls for an examination of 3-element clusters from converging treatment perspectives. This study addressed only the effectiveness and effects of teaching 3-element clusters; it did not also consider treatment efficiency. As a next step, studies are needed to evaluate the relative generalization to occur following treatment of unmarked as compared to marked onset structure. One prediction that follows from Lleó and Prinz (1996, 1997) is that treatment of branching onsets (e.g., 2- or 3-element clusters) will promote greater transfer of learning than treatment of nonbranching singleton segments (cf. Elbert et al., 1984; Powell & Elbert, 1984; Williams, 1988). An interesting consideration is whether treatment of onsets intermediate in representational complexity (i.e., affricates) will differentially influence generalization. The effect of such intermediate targets on the acquisition of more and less marked structures remains to be determined. In a related vein, it will also be necessary to determine which method of treatment may be most facilitative of generalization. In this study, we employed conventional treatment of a single target, but other methods such as a paired-stimulus (Weston & Irwin, 1971), minimal-pair (Weiner, 1981), or cycles approach (Hodson & Paden, 1991) to treatment of 3-element clusters may yield different patterns of results. The quality and quantity of input in treatment that promotes the greatest change is another efficiency issue warranting attention.

Converging evidence from complementary behavioral studies may provide further insight to the proposed segmental–syllabic interface. Thus far, the available evidence consists of cross-sectional and crosslinguistic descriptions and learning data following treatment. In future research, it may be fruitful to pursue psycholinguistic lines of study. Two paradigms that have been employed to access a child's internal representation of linguistic structure are the sorting and triad procedures (Gerken, Murphy, & Aslin, 1995; Gierut, 1996, 1998b; Treiman, 1985; Treiman & Breaux, 1982). These tasks require a child to make explicit judgments about the perceived similarity of stimuli as derived from the representation of phonological structure. In the sorting task, a child hears a standard stimulus and then judges a series of individually presented test items as either being similar (or not) to the standard. In the triad task, a child hears a stimulus triplet and then judges which 2 of 3 stimuli are similar. Sorting requires a binary "yes–no" judgment about phonological similarity, whereas the triad involves an oddity judgment. Through psycholinguistic manipulations of this type, a full range of evidence may accrue to behaviorally demonstrate the validity of the claims of linguistic theory and to modify the theory accordingly in light of contrary evidence.

In conclusion, this study has been a first attempt at identifying the necessary entry-level phonological characteristics for effective clinical treatment on the basis of the notion of linguistic complexity. Previous research has made it possible to isolate optimal treatment targets, but this study has provided preliminary insight into *who* may best respond to the treatment of those complex targets. This is an important extension, because it begins to constrain the notion of linguistic complexity in clinical treatment so as to provide a best match with an individual child's phonological system.

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Appendix. Guidelines for Constructing Nonword Stimuli.

Sixteen nonword stimuli were constructed for use in the storytelling paradigm. Nonword stimuli were unique to each 3-element cluster because some phonetic combinations of sounds resulted in a real word for a certain target cluster as opposed to others. For example, the sequence [sprin] yields a nonword for the cluster /spr-/ (as in the nonwords at right), but not for /spl-/ *spleen* or /skr-/ *screen.* To maintain the nonword status of all stimuli, the following guidelines were used in their construction (Gierut, 1999, p. 713).

The canonical shape of the nonwords included both single and multisyllabic forms. Multisyllabic nonwords had both open and closed shapes, with stress on the first syllable. There were eight target+VC, four target+VCV, and four target+VCVC forms. Half the nonwords were nouns and half verbs. The target cluster was always placed in the word-initial position. The first vowel following the cluster was selected from the pool /i, ɪ, e, ɛ, æ, ɑ, ʌ, o, ɔ, u/, and subsequent vowels in multisyllabic forms were from the further subset /i, ɑ, ə, o, u/. Subsequent consonants in the nonwords were drawn from the set /m n b d/ as sounds all children produced correctly. Sample stimuli for the target cluster /spr-/ are shown with the corresponding gloss from the story.

sprin	to run without clothes
sprɪb	a sound that monsters make
spreb	to pick a lock
sprɛm	the way alligators climb a stone wall
spræd	to trap an alligator in a cage
sprɔd	the way naughty monsters sit on a TV
sprʌn	the way naughty monsters break toys
sprum	the way Dad’s face turns blue when he is angry
sprɪmo	name of alligator
sprɛnɑ	a broken toy
sprɔbi	name of alligator’s friend
sprobu	name of boy
spridəb	name of monster
spremən	snacks that monsters eat
spronəb	alligator suitcase
sprudəm	cage for alligators