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Natural domains of cyclicity in phonological acquisition

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Abstract

This study expands and further validates cyclicity in the course of phonological development by exploring a potential relationship between the acquisition of singletons and clusters. The hypothesis is that children will acquire singletons followed by clusters in an alternating and recursive pattern, in complement to observed subsegmental cyclicity involving larnygeal and supralaryngeal distinctions. Six children with functional phonological disorders participated in one of three experimental conditions administered as a staggered multiple-baseline, multiple-probe design: treatment of singletons only, clusters only, or the singleton–cluster cycle. Results indicated that a singleton–cluster cycle could be induced experimentally, but it was not generally sustained by a child in expansion of the phonological repertoire. In comparison, laryngeal–supralaryngeal cyclicity was consistently maintained by all children, independent of experimental condition. A theoretical implication of these findings is that cyclicity functions as a governing principle of phonological development, but only if it is inherent to the natural domain of language. The clinical application of cyclicity in structuring treatment is considered.

Keywords: phonological acquisition, phonological disorders, phonological treatment, phonemic inventory, consonant clusters.

Introduction

Recursive behavioural patterns have recently been identified in the course of child development. These patterns characterize a wide range of developing systems, including the sensory system in the beginnings of sucking (Barlow, Finan and Andreatta, 1997), the motor system in the evolution of upright stepping (Thelen and Smith, 1994), the cognitive system in the formation of categories (Smith and Thelen, 1993), and the linguistic system in the emergence of phonological complexity (Mohanan, 1992). Such recursive patterns across developmental systems have given rise to the hypothesis that the course of development itself may be cyclic, and that the true task for developmental theory is to identify the relevant domains of the cycle for each system and to determine how these may interact.

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For the linguistic system, in particular, the cyclic relationships which have been identified involve the subsegmental level of representational structure. That is, children appear to expand their phonemic repertoires by elaborating featural distinctions in a recursive way. For example, in expansion of the vowel inventory, cyclicity has been observed between additions of new height, then new depth distinctions. Evidence of a cyclic height–depth relationship comes from descriptive studies of normal children acquiring Hungarian (Gierut, 1994: 20 as based on data from Fee, 1991, 1992), whereby vowel acquisition reportedly proceeds in the order (1) /a, o/, (2) /a, e/, (3) /e, i/ simultaneous with /o, u/, and (4) /u, ü/ simultaneous with /o, ö/. Height differences are represented by the emergent distinctions in (1) and (3), where a high vowel contrasts with a low vowel; whereas depth differences are noted by the vowel distinctions in (2) and (4), where a front vowel contrasts with a back vowel. Similarly, in expansion of the consonantal repertoire, cyclicity between laryngeal and supralaryngeal distinctions has been documented, such that children acquire new voice distinctions followed by place/manner distinctions in consecutive phases. Laryngeal–supralaryngeal cyclicity has been reported in descriptive studies of normal and phonologically disordered children acquiring English (Ingram, 1990, 1997; Gierut, 1994), and in experimental studies that aimed to induce the cyclic pattern in clinical treatment of children with phonological disorders (Gierut, 1996; Gierut and Morrisette, 1996).

The experimental treatment studies were especially informative because they made it possible to monitor individual differences in the implementation of laryngeal–supralaryngeal cyclicity, and to manipulate certain well-defined exclusions to the predicted cyclic patterns. Individual differences are tolerated because a notion of cyclicity does not dictate which phase will initiate the cycle. The onset of the cycle as a laryngeal or a supralaryngeal distinction is free to vary across children, and depends on an individual presenting phonemic system. Individual differences are further permitted because cyclicity does not predict the precise way in which a laryngeal or supralaryngeal distinction will manifest itself within each phase. This is underdetermined so that the same general property (either laryngeal or supralaryngeal) can be realized segmentally in different ways by different children. For instance, a supralaryngeal distinction may be effected by the introduction of a new place contrast only, a new manner contrast only, or both new places and manners relative to a child's existing sound system. Similarly, a laryngeal distinction may take the form of a voiced or voiceless counterpart to a segment that is functioning contrastively in a child's system, but it does not necessarily need to be the cognate. For example, Gierut (1996: 93) documented a case where the emergence of /z/ marked a laryngeal distinction in contrast to /f θ ʃ/. For this child the supralaryngeal characteristics of /z/ were wholly predictable from the single feature [+voice]. On the basis of a laryngeal distinction alone, /z/ was differentiated from all other continuants in this child's inventory in the absence of any cognate pairs (see Dinnsen, 1992 for comparable examples; also, Gierut, Elbert and Dinnsen, 1990 for discussion of the (non)relevance of cognates). Thus, the main consideration in establishing a contrast as laryngeal or supralaryngeal involves the featural redundancies and distinctions, and not the segmental composition, of a child's presenting phonemic system (Gierut, 1992, 1996). Finally, individual differences are allowed in the number of segments added in a given phase, and in the number of cycles completed by a child. If multiple sounds are added at a single point in time, they all mark an identical distinction, either laryngeal or supralaryngeal. If multiple cycles are completed, they conform to the more general alternating pattern of laryngeal, then supralaryngeal contrasts. The extent of phonemic expansion has been shown to be influenced by the experimental treatment manipulations and also by the phase duration (Gierut, 1994; Gierut and Morrisette, 1996).

While individual differences are allowed, cyclicity does constrain the nature and range of possible variation. Consider that, in laryngeal–supralaryngeal cyclicity, there should never be a case of a child acquiring a laryngeal distinction followed by a consecutive laryngeal distinction, with the same being true for consecutive supralaryngeal distinctions. It is also the case that there should be no instances of laryngeal and supralaryngeal distinctions emerging simultaneously. The reason is that these acquisition patterns would violate the alternating relationship between laryngeal and supralaryngeal properties. Thus far, these two well-defined exceptions constitute the conditions of falsifiability which have been put to experimental test. As explicated in Gierut (1994: 8–18), other possible, but less stringent, exclusions to laryngeal–supralaryngeal cyclicity may be associated with phase duration, phase completion, or phonotactic permissibility, thereby contributing to its falsifiability, but these remain to be established empirically.

In the prior experimental manipulations, children with phonological disorders were taught new distinctions that were either consistent with, or that violated, the cyclic laryngeal–supralaryngeal pattern. Three key findings emerged from the collective results. First, all children elaborated their phonemic inventories in a manner consistent with laryngeal–supralaryngeal cyclicity. This attested to the existence of a subsegmental cycle, and supported the proposal that laryngeal and supralaryngeal properties are represented underlyingly at the same hierarchical level of phonological structure (cf. Davis, 1989). Second, the greatest overall learning was observed for children who were taught featural distinctions that were 'out-of-phase' relative to their pretreatment phonemic repertoires. To illustrate the notion of phase relationship, consider a child who presents an asymmetry in the inventory associated with voicing. For this child, the next expected phase of the cycle (i.e., 'in-phase') would be laryngeal, whereas supralaryngeal would be 'out-of-phase' (see Gierut, 1996 for detailed discussion). Children who were taught new distinctions 'in-phase' either acquired the treated distinction or learned nothing at all. In comparison, those who were taught 'out-of-phase' first acquired the next expected (but untreated) distinction 'in-phase', then advanced to producing the treated distinction 'out-of-phase', and finally went on to propagate the cycle. Third, in order for treatment to be most effective, it was necessary to introduce laryngeal and supralaryngeal as the relevant domains of the cycle, in addition to demonstrating the recursive relationship between these properties. Together, the results supported the validity of laryngeal–supralaryngeal cyclicity, and identified the most efficacious teaching conditions that may be utilized clinically in promoting a cyclic course of phonemic expansion.

The purpose of the present study is to expand and further validate cyclicity in the course of phonological development by exploring a potential relationship between the acquisition of singletons and clusters. The hypothesis is that children will acquire singletons followed by clusters in an alternating and recursive pattern. There is preliminary empirical motivation for a singleton–cluster relationship that comes from several sources. It is well known that clusters present difficulty in acquisition for children who are normally developing, as well as for those who are phonologically disordered (Smit, 1993; McLeod, van Doorn and Reed, 1997). Also, in treatment, mastery of a cluster has been shown to facilitate the subsequent acquisition of singletons (Elbert, Dinnsen and Powell, 1984; Powell and Elbert, 1984). Further, within the specific treatment programme advanced by Hodson and Paden (1991), clusters and singletons are routinely targeted in succession. This programme of intervention has been deemed extremely successful in descriptive reports of treatment efficacy (Gordon-Brannan, Hodson and Wynne, 1992; Hodson, 1983). Perhaps, its success can be attributable to the fact that it capitalizes on the basic (cyclic) way in which the development process takes place.

Importantly, the possible relationship between singletons and clusters advances the study of cyclicity beyond the subsegmental level of representational structure. The focus shifts to subsyllabic structure, with particular emphasis on the skeletal tier which delineates the timing slots of a lexical item in word-level phonology (Kenstowicz, 1994). Singletons occupy only one timing slot (i.e. C), whereas clusters are presumed to occupy two (i.e. CC). Moreover, singleton–cluster cyclicity affords another look at laryngeal–supralaryngeal cyclicity, but within a larger and interactive context. That is, for every singleton that may be acquired in the singleton–cluster cycle, it is also expected that laryngeal–supralaryngeal cyclicity would be maintained. For example, an expected sequence might be acquisition of a cluster→acquisition of a singleton marking a laryngeal distinction→acquisition of a cluster→acquisition of a singleton marking a supralaryngeal distinction, and so on. While the particulars of the subsegmental phases of the hypothesized cluster–singleton cycle are predictable from prior evidence of laryngeal–supralaryngeal patterns, the same level of detail has yet to be determined for the intervening subsyllabic phases involving cluster acquisition (Gierut, 1998). Thus, singleton–cluster cyclicity examines recursive relationships at another level of representational structure, but it also examines interactions between levels.

This paper reports the experimental results of a test of singleton–cluster cyclicity. By way of overview, six children with functional phonological disorders participated in one of three conditions: treatment of singletons only, clusters only, or the singleton–cluster cycle. Each child was taught four targets in sequence, with intervening probes to measure generalization and change in the productive sound system. If singleton–cluster cyclicity obtains, then a primary prediction is that children who are taught a series of singletons only or clusters only will evidence the greatest learning. These children will acquire the treated, and also the untreated domains of the singleton–cluster relationship. This will be in contrast to children who are directly taught the singleton–cluster cycle, and who will likely learn only what is treated. A secondary prediction is that, regardless of experimental teaching condition, laryngeal–supralaryngeal cyclicity will be observed during the singleton phases of the putative singleton–cluster cycle.

Methods

Participants

Six children diagnosed with functional phonological disorders participated. Mean age of the children was 4;3 (range = 3;2 to 7;3). Initial entry criteria required that children perform below the 20th percentile on the *Goldman–Fristoe Test of Articulation* (Goldman and Fristoe, 1986) relative to age- and sex-matched peers, and to produce a minimum of 30 errors in singleton sound production and broad-based errors in cluster production on this measure. With exception of S49's accurate production of the target cluster /bl/, all children evidenced a global pattern of cluster reduction. More detailed analyses of children's phonological systems were developed after it was also determined that their performance was within normal limits on standard measures of hearing acuity (ASHA, 1985), oral–motor structure and function (Robbins and Klee, 1987), non-verbal intelligence (Levine, 1986), and expressive/receptive language (Hresko, Reid and Hammill, 1981; Newcomer and Hammill, 1988). All children resided in monolingual English-speaking homes and had not received prior phonological intervention.

Pretreatment phonological systems

Phonological analyses were developed from speech samples that were elicited in picture-naming tasks. Two phonological probes were utilized: the Phonological Knowledge Protocol (PKP) and the Onset Cluster Probe (OCP). The 198-item PKP samples all target English consonants in all relevant word positions in a minimum of five different exemplars (Gierut, 1985). (Target /ʒ/ is not sampled on the PKP given its frequency of occurrence and lexical predictability, cf. Labov, 1994: 328). The 146-item OCP samples all target English two- and three-element clusters in word-initial position in a minimum of five different exemplars (see appendix). As in our prior work, the words of each probe were pictured, independently randomized, and assembled in a book format for elicitation purposes. Unique picture books were developed for use in longitudinal probe administrations in order to prevent a child's productions from becoming stimulus-bound; that is, the probe words remained the same, but the pictures varied across repeated samples. Children spontaneously named the pictures on each page of the probe book, with the clinician providing relevant cues in the form of questions (e.g. 'What color is the block?') or cloze sentences (e.g. 'The boy is sitting on the ___.'). If a child did not respond spontaneously, the clinician provided further assistance in the form of delayed imitation (e.g. 'This block is blue. See the blue block. What colour is the block?'). If there was still no response, the clinician incremented the level of support to direct imitation (e.g. 'Say blue.'). Responses were coded as spontaneous, delayed, or direct imitation, with no apparent variation in responding associated with level of cueing. Speech samples were audiorecorded, and then phonetically transcribed by trained listeners using narrow notation of the IPA. The samples were analysed to determine a child's phonemic inventory of singleton segments and the minimal distance in sonority permitted in onset cluster production.

The *phonemic inventory* was defined by a conjunction of two criteria, following procedures outlined by Gierut, Simmerman and Neumann (1994). Qualitatively, a sound had to be used contrastively in two unique sets of minimal pairs, irrespective of the ambient phonology. Quantitatively, a sound was assigned phonemic status if it was also produced with a minimum of 6% accuracy relative to the ambient phonology. These criteria were invoked so as to incorporate both independent and relational considerations in a conservative estimate of the phonemic system, such that a child was required to demonstrate a certain degree of linguistic competence that also was in conformity with the target language. Sounds that met these conditions were included in the phonemic inventory; all other ambient sounds were taken to be excluded from the repertoire and served as potential treatment targets.

Onset cluster production was evaluated in terms of *sonority difference*, using procedures established in the literature that follow from the more general Sonority Sequencing Principle (Blevins, 1995; Clements, 1990; Jespersen, 1904; Kenstowicz, 1994; Selkirk, 1982; Sievers, 1881; Steriade, 1982/1990). The Sonority Sequencing Principle, which has received strong cross-linguistic validation (Blevins, 1995; Clements, 1990; Jespersen, 1904; Kenstowicz, 1994; Selkirk, 1982; Sievers, 1881; Steriade, 1982/1990), states that onsets rise in sonority to the nucleus, whereas codas fall in sonority from the nucleus. (Sonority generally corresponds to a resonant quality associated with relatively open or unconstricted air flow.) The degree of sonority that is allowed between consecutive segments in an onset is defined as the sonority difference. In calculating this difference, the sonority of each segment in a cluster was first determined on an expanded numerical scale (Steriade, 1982/1990): voiceless stops (7), voiced stops (6), voiceless fricatives (5), voiced fricatives (4), nasals (3), liquids (2), and glides (1). Then, the sonority difference between segments in the cluster was calculated. For example, given the cluster /dr/, /d/ has a sonority value of 6 and /r/, a value of 2, yielding a sonority difference of 4. Using this metric, the sonority difference was determined for each cluster produced by a child, regardless of whether it was correct relative to the ambient. A child was credited with a particular sonority difference if there was a two-time occurrence of that value. To illustrate, if the onset sequence [dr] was produced twice, a child would be credited with the sonority difference 4. As another example, if [dr] and [fw] were each produced only once, a child would be still credited with the sonority difference 4 because there was a two-time occurrence of that value. The smallest sonority difference permitted in a phonological system is known as the *minimal distance* in sonority, and is indicative of the most marked cluster type. In this study the minimal distance allowed in a child's phonology was used as the starting point for determining potential cluster treatment targets. Phonemes excluded from the pretreatment singleton repertoires and the minimal distance permitted in onset cluster production for all children are shown in table 1.

Experimental treatment

Children were randomly assigned to one of three independent experimental conditions: treatment of singletons only, clusters only, or singleton–cluster cyclicity. Two children participated in each experimental condition administered as a staggered multiple-baseline across-subjects design. In the staggered multiple-baseline design a period of no-treatment is followed by treatment, with the number of pretreatment baselines increasing by one as each successive child enters the treatment programme (Thompson and McReynolds, 1986). The baseline measures were the PKP and OCP, as described above. All ambient sounds and sound sequences sampled on these measures were monitored at the outset of treatment, regardless of their phonological status. Importantly, however, pretreatment baseline stability of 0% accurate responding was required for all sounds and sound sequences selected as treatment targets.

Within each experimental condition there was the further application of a within-subject multiple-probe design (McReynolds and Kearns, 1983). The multiple-probe design added a further degree of experimental control because each child was to receive treatment on a sequence of four ambient targets, consistent with the cyclic patterns being evaluated. In the multiple-probe design, a true baseline measure is administered just before the instatement of treatment on a particular target. The

Table 1. *Pretreatment phonological composition of each child's sound system with experimental assignment*

Subject	Chronological age (years;months)	Sex	Consonants excluded from the phonemic inventory	Minimal distance in sonority	Experimental condition	Sequential treatment targets
S58	7;3	Male	f θ s z ʃ r	4 with use of gl, dl	C only	f z s ʃ
S63	3;3	Male	θ ð z ʤ r	3 with use of fr, fl	C only	z r ʤ θ
S50	3;2	Male	θ ð ʃ ʧ ʤ l r	6 with use of pw, tw, kw	CC only	sn fl sw kr
S56	4;2	Male	s z ʃ ʧ ʤ l r	no clusters, either ambient or nonambient	CC only	sm fr bl tr
S49	4;4	Female	ŋ ð s z ʃ ʧ ʤ r	4 with use of bl, gl	C-CC	ð sn ʃ θr
S53	3;11	Male	v θ ð ʧ ʤ r l	4 with use of fw	C-CC	v sm θ fl

Note: Subject numbers were assigned consistent with a larger project on the development of phonological categories.

true baseline ensures that the particular target has not improved as a consequence of prior treatment on other targets in the teaching sequence. In this study, the true baseline measures were the specific subset of PKP and OCP items that sampled a given target. Again, 0% accurate responding on the true baseline measures was required for treatment to proceed.

In all experimental conditions, and for all targets, treatment consisted of two phases: imitation followed by spontaneous production. The imitation phase continued until a child achieved 65% accurate production of the target, or until two sessions were completed (i.e. 200 trials), whichever occurred first. Treatment then shifted to the spontaneous mode, and continued until a child achieved 80% accurate production of the target over two consecutive sessions, or until four sessions were completed (i.e. 400 trials), whichever occurred first. Treatment followed an established non-word story-telling procedure (Gierut, 1992; Schwartz and Leonard, 1982). For each target, 10 phonotactically permissible non-words were developed and balanced for phonetic context, syllabic structure, and syntactic category. Non-words were introduced in children's stories and served as the referents for various characters and their actions. Stories were read to a child weekly, and line drawings of the non-words were used in the production practice. Treatment sessions were held three times weekly, with each session being 1 hour in duration. The average time in direct treatment for children of this study was 16 sessions.

Treatment targets

For each child, four target sounds and/or sound sequences were selected for treatment based on the results of the pretreatment phonological analyses, and varied by experimental condition. These are listed in table 1. Four targets were selected because this would potentially allow for the completion of two cycles, thereby demonstrating both the domain and phase relationship of recursive phonological patterns (cf. Gierut and Morrisette, 1996).

In treatment of singletons only, children were taught four phonemes excluded from their pretreatment repertoires and produced with 0% accuracy. Phonemes selected for treatment represented consecutive laryngeal and supralaryngeal phases of the subsegmental cycle. For methodological consistency across subjects, treatment always began in the laryngeal phase because there has been no difference reported in the starting phase of the cycle and extent of phonological learning (Gierut, 1996). The particular phonemes selected for treatment were determined from observed asymmetries in children's pretreatment sound systems, following methods outlined in Gierut (1996).† Specifically, S58 exhibited a voicing asymmetry in production of

†It is not the intent of this paper to establish how observed asymmetries in the children's pretreatment sound systems may have come about from earlier points in time. This would require that a longitudinal history of phonemic emergence be available for each child, which it was not. However, based on other retrospective and experimental demonstrations of subsegmental cyclicity, it is possible to speculate that observed asymmetries may have resulted from multiple segments being added in a given phase of the laryngeal–supralaryngeal cycle, or from segments being added in a non-cognate sequence. For example, S58 of this study may have acquired the voiced continuants /v ð/ simultaneously in a supralaryngeal phase of the cycle. Similarly, S63 may have added the three voiceless obstruents /s ʃ ʧ/, also in a supralaryngeal phase. For retrospective applications of laryngeal–supralaryngeal cyclicity, and further discussion of the simultaneous emergence of multiple segments and the non-necessity of cognate relationships, the reader is referred to Gierut (1994, 1996).

continuants, such that all fricative phonemes were predictably voiced. The child used /v/, but not /f/ phonemically. Hence, treatment began with /f/, thereby introducing a laryngeal contrast among labial fricatives. The next target in the treatment sequence was to involve a supralaryngeal distinction, and /z/ was selected. With treatment of /z/, a manner contrast between distributed (i.e. /ð/ which was already in the pretreatment repertoire) and non-distributed (i.e. /z/) coronal fricatives was introduced, with voicing in this series remaining wholly predictable. The third target was /s/, as the laryngeal counterpart to /z/. The final target was /ʃ/, completing a supralaryngeal phase of the cycle. S63 presented a similar case of laryngeal asymmetry, and served as an appropriate replication. For this child, coronal obstruents /s ʃ ʧ/ were predictably voiceless prior to treatment. Treatment thus began in the laryngeal phase with the target /z/, followed by /r/ (supralaryngeal), /ʤ/ (laryngeal), and /θ/ (supralaryngeal). It should be noted that, beyond the initial phase of the laryngeal–supralaryngeal cycle, the particular targets selected for treatment were somewhat arbitrarily determined. As in prior studies of cyclicity, it would remain to be determined how a given child would internalize and mark the subsegmental distinctions of the treated target.

In treatment of clusters only, four ambient clusters that were produced with 0% accuracy were targeted for each child. The particular clusters selected for treatment conformed to three criteria. First, treated clusters were obstruent + sonorant sequences to provide consistency among subjects in the type of onset sequences being taught. Second, at least one member of the treated cluster had to be in a child's singleton repertoire to provide uniformity in the nature of the learning task. Third, treated clusters were of a sonority difference that was equal to or less than the minimal distance allowed in a child's pretreatment repertoire. For example, if a child produced clusters with a minimal sonority distance of 5, then treated clusters could be selected from the values 5, 4, 3, or 2. This was an important consideration because minimal sonority distance translates to markedness: the smaller the sonority difference, the more marked the cluster (Clements, 1990). The third criterion in cluster selection thus ensured that all children would be exposed to clusters of equal or greater difficulty than those already being used in their pretreatment systems. Treatment of clusters always began with the most marked cluster value given the reported positive effects of markedness on phonological learning (for review see Gierut, Morrisette, Hughes and Rowland, 1996). The two children enrolled in the cluster condition were taught clusters of sonority values 2, 3, 4, and 5, in that sequence. Targets for S50 were / sn, fl, sw, kr/, and for S56, /sm, fr, bl, tr/. As with singletons, the specific clusters were rather arbitrarily selected as long as they met the conditions above.

In treatment of the singleton–cluster cycle, the four targets represented each of the cyclic domains, such that treatment began with a singleton followed by a cluster in sequential alternation. Consistent with the prior experimental conditions, a laryngeal contrast was always introduced first during singleton phases, and a relatively more marked cluster was always introduced first during cluster phases. S49 began treatment with the singleton /ð/ which represented a new laryngeal distinction, given the child's phonemic use of /θ/. This was followed by the cluster /sn/ of a sonority difference of 2. The next target was the singleton /ʃ/, representing a new supralaryngeal distinction for this child, and the final target was cluster /θr/, with a sonority value of 3. S53 followed the same laryngeal→sonority difference$_2$→ supralaryngeal→sonority difference$_3$ teaching sequence, with the targets being /v, sm, θ, fl/, respectively.

Evaluation of potential cyclic change

Throughout treatment, the PKP and OCP were administered longitudinally to monitor changes in the composition of a child's phonemic inventory and use of onset consonant clusters. In addition to the pretreatment sample, these phonological data were obtained at phase shifts of treatment, immediately post-treatment, 2 weeks, and 2 months post-treatment, with an average of 16 samples obtained for each child approximately every 12 calendar days. Samples were audiorecorded and phonetically transcribed, and an estimate of interjudge transcription agreement was calculated for 30% of all probe data obtained from each child. A trained judge independently retranscribed the samples from the audiorecordings, and mean point-to-point consonant transcription agreement was 90% (5230 consonants transcribed). Notably, only 3% of consonants transcribed involved differences that directly related to phonemes or clusters excluded from a child's pretreatment repertoire and relevant to the experimental treatment manipulations.

Longitudinal phonological data were used to evaluate the proposed singleton–cluster cycle. Of concern were the new sounds and clusters added to a child's phonological repertoire, and the order in which these new contrasts emerged. The working assumption was that phonological properties that were first acquired would emerge at earlier points in time and would be used with greater overall accuracy (Ingram, 1988; Locke, 1983; Pye, Ingram and List, 1987). To determine which properties were added to a child's repertoire, the following criteria were employed (Gierut, 1994, 1996; Gierut and Morrisette, 1996): (1) a phoneme or cluster had to be used contrastively by a child as evidenced by two unique sets of minimal pairs and a minimum of 6% production accuracy relative to the ambient phonology, and (2) the occurrence of minimal pairs had to be maintained across consecutive samples continuing to 2 months post-treatment. These conditions ensured that the properties claimed to be newly acquired by a child were, in fact, distinctive, accurate, and stable. Once the new contrasts were determined, then it was necessary to plot their apparent order of acquisition. Mean production accuracy of each new contrast was calculated across probe samples and rank-ordered from increasing to decreasing accuracy. This was taken as a reflection of the longitudinal sequence in which the newly acquired contrasts emerged, and was used in evaluation of claims of singleton–cluster cyclicity. As discussed at length in Gierut (1994: 12), the documentation and confirmation of a longitudinal sequence of phonological acquisition is inherently problematic to the study of developing systems in general. Methodologically, it is impossible to trace minute-by-minute changes in a child's productive phonology. There always exists the possibility that crucial data are missed in sampling, or that emergent distinctions are overlooked. Consequently, the criteria and procedures to support claims about the course of phonological acquisition must be operationalized. In this and prior work on cyclicity, we have opted to strictly apply converging metrics to discern whether a new contrast was established, at what point in time it was acquired, and how well it was internalized so as to provide the most conservative, replicable estimate of a child's expansion of the phonological system. These metrics follow from, and extend, procedures that have been outlined in previous studies of developing (Ferguson and Farwell, 1975; Leonard, Newhoff and Mesalam, 1980; Locke, 1983; Pye *et al.*, 1987; Stoel-Gammon, 1985; Stoel-Gammon and Cooper, 1984) and fully developed systems (Maddieson, 1984).

Results and discussion

Results are presented in table 2 for each child by experimental condition. These data plot the order of emergence of new singletons and clusters in a child's repertoire. The data reflect which new phonological properties were added to a child's sound system, and the order in which these were learned. The data are discussed for each experimental manipulation relative to the primary issue of subsyllabic cyclic patterns in the acquisition of singletons and clusters. A secondary issue to be discussed is whether the data provide further supporting evidence of a subsegmental pattern of laryngeal–supralaryngeal cyclicity.

Treatment of singletons only

The two children enrolled in this experimental condition each acquired only two of the four treated singletons, as in table 2. S58 was taught /f, z, s, ʃ/ in consecutive sequence, and learned /f, ʃ/ in that order. This child did not acquire any untreated clusters or singletons. Similarly, S63 was taught /z, r, ʤ, θ/, but learned only the subset /ʤ, z/. S63 did acquire one untreated cluster /tw/, which emerged last in the sequence of acquisition.

The limited learning evidenced by these children offered little insight to a potential subsyllabic relationship between singletons and clusters. There was no substantive expansion of the children's repertoires in the cluster domain, but S63 did appear to superficially follow a singleton–cluster order of acquisition. The overall extent of learning for these children was also extremely shallow. Perhaps this is due to the fact that singletons were introduced 'in-phase' relative to children's pretreatment inventories. Recall that, in prior treatment studies, greater phonological gains followed an 'out-of-phase' teaching sequence whereby consecutive distinctions of the same type (e.g. supralaryngeal only or laryngeal only) were introduced (Gierut and Morrisette, 1996). In the absence of more extensive phonological expansion, it is not possible to unambiguously confirm or reject the presumed singleton–cluster cycle for this particular experimental manipulation.

This notwithstanding, with regard to the treated class of singletons, children did follow the expected laryngeal–supralaryngeal cycle of inventory expansion. In particular, for S58, the addition of /f/ to the phonemic inventory marked an emergent laryngeal distinction in contrast to this child's pretreatment phonemic use of /v/. The subsequent addition of /ʃ/ was indicative of a supralaryngeal distinction within the coronal fricatives. Prior to treatment, S58's repertoire was limited to the use of /ð/, an anterior, distributed coronal fricative. The use of /ʃ/ now provided a place/manner contrast involving a *non*-anterior, *non*-distributed coronal fricative. S58 thus completed two phases of the laryngeal–supralaryngeal cycle. Similarly, S63 added both expected laryngeal distinctions to the inventory in parallel to the general asymmetry that restricted coronal obstruents to the voiceless /s ʃ ʧ/ prior to treatment (recall that /ʒ/ was not sampled on the probe).

Thus, following treatment of singletons only, there was insufficient evidence to draw firm conclusions about recursive patterns involving subsyllabic structures, but subsegmental relationships between laryngeal and supralaryngeal properties were maintained.

Table 2. *Order of emergence of new singletons and clusters for each child by experimental condition*

Experimental condition	Subject	Order of emergent phonological properties																							Cyclicity
C only																									
	S58	f C L	ʃ C SL																						C-CC? No L-SL? Yes
	S63	ʤ z C L	tw CC																						C-CC? Yes L-SL? Yes
CC only																									
	S50	sn CC	ʧ C SL	skw CCC	sm CC	ʤ C L	tw CC	Cj CC	ʃ C SL	sw CC	sp CC	sk CC	tr CC	dr CC											C-CC? No L-SL? Yes
	S56	Cj CC	tw CC	kw CC	sk CC	sm CC	sn CC	sp CC	st CC	gl CC	skw CCC	ʤ C SL	kl CC	sw CC	bl CC	ʧ C L	s C SL	sl CC	fl CC						C-CC? No L-SL? Yes
C-CC																									
	S49	ŋ C SL	sn CC	ð C L	sm CC	sl CC	sk CC	sp CC	skw CCC	Cj CC	spl CCC	ʤ C SL	ʧ C L	θr CC	dr CC	st CC	z C SL	s C L	skr CCC	gr CC	str CCC	tr CC	ʃ C SL	fr CC	C-CC? Yes, in part L-SL? Yes
	S53	l C SL	v C L	pl CC	θ C SL	bl CC	ð C L																		C-CC? Yes, in part L-SL? Yes

Note: C and CC describe the phonological property as singleton or cluster, respectively; L and SL describe the singleton distinction as laryngeal or supralaryngeal, respectively.

Treatment of clusters only

As in treatment of singletons only, the two children enrolled in this experimental condition only learned a subset of the treated clusters. However, in sharp contrast to the singleton condition, these children evidenced broad generalization, with acquisition of untreated clusters and untreated singletons. S50 acquired three singletons, nine two-element clusters, and one three-element cluster, whereas S56 acquired three singletons, 14 two-element clusters, and one three-element cluster. As in table 2, the order of acquisition of these new contrasts did not follow a strict ordering of singletons then clusters, but other distinct patterns emerged.

In particular, with regard to the treated class of clusters, a pattern of within-class generalization associated with the treated targets was observed. To illustrate, S56 acquired treated /sm/ and /bl/, but not treated /fr/ or /tr/. Related to this, the child expanded the cluster repertoire to include untreated clusters of the types /sC/ and /Cl/. Within the /sC/ series, the clusters /sk, sm, sn, sp, st, skw, sw/ were added in sequence. For the /Cl/ series, the clusters /gl, kl, bl, sl, fl/ were sequentially added. Interestingly, in both instances of sequential cluster acquisition for this child, the treated targets /sm/ and /bl/ were *not* the first clusters of that particular type to emerge. A similar pattern of sequential within-class generalization of clusters was also evident for S50, particularly with regard to the /sC/ and /Cr/ categories.

Another pattern related to the acquisition of untreated singletons. Both children expanded their inventories by adding three new singletons, indicative of the phases supralaryngeal→laryngeal→supralaryngeal. S50 acquired in order /ʧ, ʤ, ʃ/. Prior to treatment, there were no affricates in the child's repertoire, and fricatives were limited to labials /f, v/ or coronals /s, z/. The addition of /ʧ/ first represented a new supralaryngeal distinction between simple and contour segments. This was followed by a laryngeal distinction involving the voiced counterpart /ʤ/. Lastly, coronal /ʃ/ signalled a new supralaryngeal distinction between anterior and non-anterior coronal fricatives. The acquisition of singletons for S56 was nearly identical with the consecutive emergence of /ʤ, ʧ, s/.

In sum, following treatment of clusters only, there was broad generalization with acquisition of both treated and untreated clusters and singletons. A subsyllabic pattern of singleton–cluster cyclicity was not maintained; however, a subsegmental pattern of laryngeal–supralaryngeal was.

Treatment of a singleton–cluster cycle

For the two children who were taught the presumed singleton–cluster cycle, both clusters and singletons emerged. S49 acquired seven singletons, 12 two-element clusters, and four three-element clusters, adding 23 new phonological contrasts to her repertoire. This child learned all four of the treated targets. The pattern of acquisition for S53 was less extensive by comparison, with acquisition of four singletons and two two-element clusters. For this child, not all treated targets were actually acquired.

When the data from these children are considered relative to a cyclic relationship between singletons and clusters, a limited pattern emerges early in the acquisition sequence. Table 2 shows that S49 first acquired an untreated singleton /ŋ/, marking a supralaryngeal contrast. This was followed by the treated cluster /sn/. /sn/ emerged specifically as a complex onset in this child's system because the singleton /s/ by itself did not meet the strict criteria of contrastiveness, accuracy, and stability until much later in the acquisition course. Continuing for S49, the next segment to emerge was a treated singleton /ð/, indicative of a laryngeal distinction, followed by acquisition of the untreated cluster /sm/. To this point in the course of acquisition there was a predicted sequence of $\text{singleton}_{\text{laryngeal}} \rightarrow \text{cluster} \rightarrow \text{singleton}_{\text{supralaryngeal}} \rightarrow \text{cluster}$. After this, however, the cycle broke down because S49 next learned six consecutive clusters, two consecutive singletons, three consecutive clusters, and so on following from table 2. A pattern of singletons followed by clusters in sequence was also observed for S53, but for this child the cycle appeared to continue throughout the entire course of acquisition. Yet, because the extent of learning was more restricted for this child, it is not clear whether the recursive pattern would have been sustained as additional contrasts were learned, or whether it would break down as for S49. Thus, a conservative statement is that a singleton–cluster cycle can be induced in treatment, but it does not seem to be systematically assumed by all children.

In examination of the acquisition of singletons alone and clusters alone, the results of this experimental condition are wholly consistent with, and reinforce observations of, the prior experimental conditions. Specifically, laryngeal–supralaryngeal cyclicity was upheld for both children, as best exemplified by the learning path of S49. This child acquired in sequence supralaryngeal /ŋ/→ laryngeal/ð/→supralaryngeal /ʤ/→laryngeal /ʧ/→supralaryngeal /z/→laryngeal /s/→supralaryngeal /ʃ/. It is significant that the only treated singletons were /ð/ and /ʃ/, but nevertheless, the order of acquisition conformed to the subsegmental cycle. In acquisition of clusters, principles of within-class generalization again appeared to guide the course of learning, with the emergence of clusters of a particular type occurring in sequence. For S49, sequential within-class generalization patterns involved /sC/ clusters, reflected by the acquisition order /sn, sm, sl, sk, sp, skw, spl/, as well as /Cr/ clusters. For S53, sequential within-class generalization was limited to the class of /Cl/ clusters, namely, /pl, bl/.

To summarize, treatment of a singleton–cluster cycle appeared to induce a recursive acquisition pattern, but it was not systematically sustained. As in prior experimental conditions, laryngeal–supralaryngeal cyclicity was observed, regardless of whether the acquired distinctions were treated or untreated. In addition, patterns of within-class generalization in cluster acquisition were again observed.

Conclusion

The collective results of this study raise several issues about the domain of cyclicity in phonological acquisition, and hold implications for an appeal to cyclicity in structuring clinical treatment.

Cyclicity in the natural design of language

In this study we hypothesized that cyclic patterns involving singletons and clusters may define the course of phonological acquisition at the subsyllabic level of representational structure. The results of this study, however, suggest that a recursive pattern of this sort may be tentative at best. The only experimental condition that unambiguously supported a singleton–cluster cycle was that which directly treated the cycle itself. Yet, while a singleton–cluster cycle could be induced within this experimental condition, it was not generally sustained. Children were able to tap into and utilize a singleton–cluster cycle in the earliest phases of phonological acquisition, but when left to further elaborate their sound systems this cycle did not function as a governing principle of development. The inadequacy of singleton–cluster cyclicity as a formal linguistic condition is further confirmed by the experimental manipulations that involved treatment of singletons or clusters only. In these manipulations there was no observed cyclic relationship between singletons and clusters. Children did not acquire the intervening, untreated phases of the proposed cycle in strict sequence, as might have been predicted. Instead, following the sequential treatment of singletons, the emergence of untreated clusters was lacking almost in entirety. Following the sequential treatment of clusters, untreated singletons emerged, but not in a patterned relationship with the treated clusters. Together, these data imply that, while a cyclic course of acquisition may be induced with treatment, it will not be sustained if it is not part of the natural domain of language.

This premise receives strong support when the results of cyclicity at a subsegmental level of representation are considered. The proposed cyclic relationship between featural distinctions involving laryngeal–supralaryngeal contrasts was observed across all three experimental conditions and for all six children. When a child acquired singletons, the distinctions that emerged marked laryngeal, then supralaryngeal properties in synchrony. This was true despite the fact that not all children were exposed to singletons in treatment, as in the case of those who were taught clusters only. Further, the recursive pattern held even when singletons were treated, but not acquired. These data underscore the robustness of subsegmental cyclicity involving laryngeal and supralaryngeal properties, and add to the available replications of the recursive featural pattern. A broader implication is that laryngeal–supralaryngeal cyclicity as a linguistic principle of acquisition is an inherent, and not artifactual, aspect of language. It can be induced in treatment, but it will also be maintained independent of treatment.

Although the present data do not support cyclicity at a subsyllabic level of structure, this should not be interpreted to mean that recursive relationships are nonexistent across levels of phonological structure; rather, the singleton and the cluster may not be the relevant defining properties. There may be at least two possible reasons for this. First, cyclicity may only be a governing property within, but not across, levels of structure. Recall that the proposed singleton–cluster cyclicity involved a recursive pattern at the higher-order subsyllabic level of structure, but it also entailed an interaction with subsegmental levels of structure. If we were to explore cyclicity more narrowly, then one possible subsyllabic domain may be associated solely with clusters themselves. For instance, there is preliminary descriptive evidence to suggest relationships between the emergence of onset and coda clusters, such that there will be expansion of onset clusters only following expansion of coda clusters (Lleó and Prinz, 1996). It may be then that the relevant cyclic domains of subsyllabic structure are the onset and coda cluster. This potential relationship remains an area for future experimental investigation.

A second possible reason why cyclicity at the subsyllabic level may have been restricted relates to known implicational relationships. Specifically, the occurrence of clusters in a language implies the occurrence of singletons, but not vice-versa. This is a unidirectional relationship between the presumed domains of the singleton–

cluster cycle, and it differs from the independent relationship that obtains between laryngeal and supralaryngeal distinctions. Perhaps recursive patterns of learning will be observed only when independent structural domains are involved. The extent of cyclicity in acquisition of independent versus implicationally related components of language is another line of research to be explored.

Cyclicity in the structure of clinical treatment

The results of this study also have implications for clinical treatment and its structure. Of significance is the fact that children who were taught clusters only, or clusters in alternation with singletons, evidenced the greatest expansion of the sound system. These children acquired both treated and untreated singletons and clusters, learning from six to 23 new phonological contrasts. This is in comparison to children in the singletons-only condition, who learned only a very limited subset of treated distinctions. One treatment suggestion that derives from this outcome is that children should be taught clusters for the greatest system-wide generalization to occur. This recommendation is also consistent with the growing body of treatment research that appeals to markedness relationships to facilitate the greatest generalization learning (Gierut *et al.*, 1996 for review). It is important to note that in this study, in the treatment of clusters, markedness was realized in two ways. The general relationship was that treated clusters were more marked relative to singletons, and the specific relationship was that treated clusters were selected relative to pretreatment minimal distances in sonority. Recall that all children were taught clusters equal to or more marked than those in their pretreatment repertoires. A next appropriate treatment extension will be to determine whether comparable generalization patterns will also obtain following treatment beginning with unmarked clusters in sequence (Gierut, 1998).

Alternatively, if treatment of singletons remains the goal of teaching, then the extent of generalization learning may be expected to be more limited. Yet, given the robustness of the laryngeal–supralaryngeal cycle, one clinical recommendation may be to capitalize on this inherent principle of language development. Consistent with prior studies, generalization may be facilitated by teaching children distinctions that are 'out-of-phase' relative to their pretreatment inventories (Gierut, 1996; Gierut and Morrisette, 1996). By teaching consecutive distinctions of the same type 'out-of-phase', a child will predictably acquire the intervening untreated phases of the laryngeal–supralaryngeal cycle, thereby resulting in greater learning.

Whether treatment emphasizes clusters or singletons, this study highlights recurring themes from the treatment literature, and introduces new ones. We have already noted that markedness may be used to facilitate phonological learning. Also, the data demonstrate that particular phonological properties may be taught, but these may not be internalized by the child. Nonetheless, exposure to such targets does promote within-class generalization. Finally, cyclicity may be induced in treatment, but it will function as a governing principle of phonological development only if it is inherent to the natural domain of language.

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Appendix: Probe of onset clusters

pr	pretzel	**fr**	fruit	**gl**	glasses	**sm**	smell	**skr**	scream
	princess		frog		glove		smile		scratch
	pretty		front		glue		small		scrub
	prize		french fries		globe		smoke		scribble
	present		friend		glow		smooth		screw
br	bread	**θr**	three	**fl**	fly	**sn**	sneeze	**skw**	squeak
	brush		throw		flower		snowman		square
	broom		thread		flag		snake		squirrel
	bridge		throne		flute		snail		squeeze
	brown		throat		floor		snack		squirt
tr	tree	**ʃr**	shrink	**sp**	spill	**sw**	swing	**tw**	twinkie
	truck		shred		spider		swim		tweety
	train		shrub		spaghetti		sweep		twelve
	trick-or-treat		shrug		spoon		sweater		twins
	triangle		shrimp		space		sweet		twist
dr	dress	**pl**	plate	**st**	stop	**spr**	spread	**kw**	quack
	drum		plane		stove		sprite		queen
	drive		plant		star		spring		quarter
	draw		play		store		spray		quiet
	drink		plug		stamp		sprinkle		quilt
kr	crayon	**bl**	black	**sk**	skunk	**spl**	splash	**Cj**	music
	cry		blocks		skirt		splinter		viewmaster
	crawl		blow		school		split		cute
	crack		blanket		skate		splitting		few
	cream		blue		scarf		splashing		beauty
gr	grass	**kl**	clean	**sl**	sleep	**str**	stripe		
	green		clown		sled		street		
	grow		clock		slide		straw		
	grapes		clothes		slipper		straight		
	grandma		cloud		sleeve		strong		