Triggering a principle of phonemic acquisition

JUDITH A. GIERUT and MICHELE L. MORRISETTE

Department of Speech and Hearing Sciences, Indiana University, Bloomington, Indiana 47405, USA

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Abstract

This experimental clinical study evaluated different treatment manipulations of the principle of Laryngeal-Supralaryngeal Cyclicity as a follow-up to Gierut (1994b). Laryngeal-Supralaryngeal Cyclicity states that the acquisition of phonemic distinctions will occur as a bivalent cycle with laryngeal and supralaryngeal distinctions emerging in turn. In this study, children with seemingly static phonemic systems participated in a treatment programme that introduced sequentially new distinctions to the inventory. One child was presented with alternating laryngeal and supralaryngeal properties consistent with the principle, whereas the other child was exposed only to consecutive supralaryngeal distinctions. Results indicated that the latter treatment condition triggered greater phonemic expansion, as based on the longitudinal course of emergent phonemic distinctions for each child. These findings were comparable to those of the earlier investigation, and have implications for treatment efficacy and theories of language acquisition.

Keywords: phonological theory, phonological disorders, phonological treatment

Introduction

In the clinical treatment of phonological disorders in children there is a puzzling relationship between teaching and learning. In particular the sounds, distinctions, and properties of the target phonology that will be acquired by a child are not predictable from the treatment in a direct or absolute way. What a child will acquire in treatment is not obvious *a priori*. For example, in the best-case scenario, a child will acquire both treated and untreated properties of the target sound system (e.g. Costello and Onstine, 1976; Fey and Stalker, 1986; Gierut, Elbert and Dinnsen, 1987; McReynolds and Bennett, 1972; Powell and Elbert, 1984). It is also possible that a child will acquire the treated property, but not other untreated aspects of the target phonology (e.g. Leonard and Brown, 1984; Weiner, 1981). Conversely, the treated property may remain unchanged, with improvements observed only in untreated components of the system (e.g. Rockman and Elbert, 1984; Tyler and Figurski, 1994). Finally, there may be no immediate evidence of phonological change with clinical treatment (e.g. Elbert, Powell and Swartzlander, 1991; Saben and Costello Ingham, 1991). Variations in patterns of learning such as these have been cited both within and across children. In an attempt to capture these individual differences in a predictable way, the factors that influence the nature and extent of phonological learning in treatment have been widely explored (Dinnsen, Chin, Elbert and Powell, 1990; Dinnsen and Elbert, 1984; Elbert, Dinnsen and Powell, 1984; Forrest, Weismer, Hodge, Dinnsen and Elbert, 1990; Gierut,

Figure 1. *The principle of Laryngeal-Supralaryngeal Cyclicity: laryngeal and supralaryngeal properties of a phonological system will be elaborated in continuous cycle, with expansion of the inventory first in one domain of the representation and then the other, but not with change occurring in both domains simultaneously.*

1992; Gierut *et al.*, 1987; Powell, Elbert and Dinnsen, 1991; Tyler, Edwards and Saxman, 1990). However, to date, an explanatory account of these patterns that is theoretically based, testable, adequate, and integrated remains unavailable. Preliminary insights, however, may come from a recently proposed principle of phonemic acquisition that involves Laryngeal-Supralaryngeal Cyclicity.

Laryngeal-Supralaryngeal Cyclicity was first advanced to account for symmetric and asymmetric patterns observed in phonemic acquisition by phonologically delayed children (Gierut, 1994a; Gierut, Simmerman and Neumann, 1994). The principle proposes that expansion of the phonemic repertoire will proceed as a continuous bivalent cycle with elaboration of the inventory alternating between the emergence of laryngeal (voice) and supralaryngeal (manner and/or place) properties, as in Figure 1. As it is formulated, the principle assumes a degree of subsegmental structure in the representation of phonological information (cf. Clements, 1985, 1987), and further that elaboration of distinctive properties emerges from predictable properties of the system (cf. Archangeli, 1988). The principle does not indicate which phase—laryngeal or supralaryngeal—will initiate the cycle for a given child, nor does it predict the specific phonological distinctions to emerge within each phase. These are underdetermined and free to vary, thereby allowing for individual differences across children. Of importance are two well-defined exclusions to the principle which have served to motivate empirical evaluations of its validity. In particular, the principle excludes the simultaneous emergence of two *different* distinctions in the *same* phase of the cycle (i.e. laryngeal + supralaryngeal), and the emergence of the *same* distinction across consecutive phases of the cycle (i.e. laryngeal → laryngeal or supralaryngeal → supralaryngeal).

Thus far, certain aspects of the principle have been evaluated descriptively and experimentally. The descriptive evaluation involved a comparison of the sound systems of 15 phonologically delayed children at two static points in time (Gierut, 1994a). The aim was to establish that the longitudinal order of emergent phonemic distinctions was consistent with the principle, thereby providing preliminary evidence of its validity. The experimental evaluation went on to test further the psychological reality of the principle by examining the phonemic learning of seven phonologically delayed children on-line during clinical treatment (Gierut, 1994b). The purpose of this paper is to extend the experimental evaluation by re-examining the phonemic systems of two of the children. These subjects were of particular interest because neither child elaborated the phonemic system in any way despite approximately 2000 treatment trials and 4 months of intervention. To establish the learning histories of these children, and by way of introduction, the previous experimental findings are briefly summarized.

Experimental tests

A single-subject staggered experimental evaluation of Laryngeal-Supralaryngeal Cyclicity was conducted. Subjects were assigned to one of four experimental groups. In each group, one target sound excluded from the child's phonemic repertoire was illustrative of either a manner or place distinction. The manner distinction was either in-phase or out-of-phase with the cycle, as determined from asymmetries in the child's phonemic repertoire. Thus, the domain of the sound being manipulated was independent of the phase of the cycle. The emergence of phonemic distinctions was evaluated. Three general findings emerged: (1) there was cyclicity; (2) there were no children taught a laryngeal as opposed to a supralaryngeal out-of-phase with the cycle evidence greater than with the cycle.

The latter finding is of particular interest. Among the groups were quite different results. The cycle acquired at least four laryngeal cycles. In contrast, the supralaryngeal cycle, nothing at all. These results raise the question of out-of-phase evidence greater than with the cycle. Children taught in-phase evidence greater than with the cycle.

The answer to the first question is that for a child to acquire a treated distinction, the cycle has to be completed first if the child is in the experimental group appeared in the cycle. In the treated phase of the cycle. In the untreated phase of the cycle, then added to the cycle. While continued in the cycle. While continued in the cycle, the reason for the second question: Why did some children not learn phonemic learning?

In particular, two of the children who had no distinctions in-phase evidence greater than with the cycle. Their phonemic repertoires remained exactly the same. Phonemic learning was generally consistent with the principle. It was observed for the subjects who were taught the specific results of these two children. The validity of the principle. While continued in the cycle. While continued in the cycle, the reason for the second question: Why did some children not learn phonemic learning?

One other contributing factor to the hypothesis of the present study is the lack of available intelligence and language-matched peers.

Experimental test of Laryngeal-Supralaryngeal Cyclicity

A single-subject staggered multiple-baseline design was employed in the initial experimental evaluation of Laryngeal-Supralaryngeal Cyclicity (Gierut, 1994b). Children were assigned to one of four experimental groups, with each child receiving treatment on one target sound excluded from the pretreatment phonemic inventory. The treated sound was illustrative of either a new laryngeal or supralaryngeal distinction. Further, this distinction was either in-phase or out-of-phase in the cycle, with the phase relationship determined from asymmetries in the composition of a child's pretreatment phonemic repertoire. Thus, the domain of the cycle and the phase relationship of the cycle were manipulated as independent variables. The dependent variable was the longitudinal emergence of phonemic distinctions as monitored on probes of treated and untreated sounds. Three general findings emerged: (1) the course of acquisition for all children was consistent with cyclicity; (2) there were no differences in phonemic acquisition between children taught a laryngeal as opposed to a supralaryngeal distinction; and (3) children taught out-of-phase with the cycle evidenced greater phonemic learning than those taught in-phase with the cycle.

The latter finding is of particular relevance to the present study because differences among the groups were quite remarkable. Specifically, children taught out-of-phase with the cycle acquired at least four new phonemes, thereby completing two laryngeal-supralaryngeal cycles. In contrast, those taught in-phase acquired either the treated phoneme or nothing at all. These results raised two additional questions: (a) Why should children taught out-of-phase evidence greater phonological learning? (b) Why in some cases should children taught in-phase evidence no phonological learning?

The answer to the first question is in part derivable from the principle itself. That is, for a child to acquire a treated distinction out-of-phase, the next expected phase of the cycle has to be completed first if the principle is to hold. Stated another way, children of this experimental group appeared to fill-in the expected distinction before advancing to the treated phase of the cycle. Importantly, teaching out-of-phase had a further consequence of perpetuating the cycle beyond the treated phase. Thus, children acquired the expected but untreated phase, then added the treated phase, and subsequently continued to advance in the cycle. While continued propagation of the cycle was beneficial to the sound systems of these children, the reason for this effect is not readily apparent until examination of the second question: Why did some subjects taught in-phase with the cycle evidence no phonemic learning?

In particular, two of the four children (i.e. Subjects 4 and 2) taught new phonemic distinctions in-phase evidenced absolutely no elaboration of the inventory. Their phonemic repertoires remained exactly the same pre- to post-treatment. On the one hand, the lack of learning was generally consistent with group patterns given that minimal phonemic change was observed for the subjects assigned to this experimental condition. On the other hand, the specific results of these two children did not contribute positively or negatively towards the validity of the principle. With this in mind, several external factors were considered as potential contributors to the lack of learning for these two children. It was found that the static nature of these phonemic systems could not be traced to the particular distinction being taught, the specific treated sound, or the reduced size of the pretreatment inventories of these children. Also, the children did not overtly evidence broad-based learning problems because available intelligence and language scores indicated that they were functioning as their age-matched peers.

One other contributing factor was suggested, however, and this possibility forms the hypothesis of the present study. Namely, clinical treatment itself may have been

insufficient in triggering the cycle. In accord with the principle, there are presumably two components a child must initiate in phonemic acquisition: the linguistic dimensions of the cycle and the consecutive phases of the cycle. Some children may require more than just exposure to a single domain of the cycle, as was the structure of clinical intervention in Gierut's (1994b) earlier experimental study. Perhaps what is also needed is an explicit demonstration of cyclicity itself through direct and sequential treatment of laryngeal and supralaryngeal properties. This notion of introducing cyclicity explicitly may also be associated with why the children taught out-of-phase propagated the cycle beyond what was treated. While these children were taught only one domain of the cycle out-of-phase, the nature of their learning patterns inadvertently caused them to be exposed also to the alternating phase relationship of the cycle. Because children filled-in untreated distinctions in the course of acquiring the treated distinction out-of-phase, they were able to observe both phases of the cycle directly.

In order to test the hypothesis of an alternate and cyclic treatment structure in the present study, the two children who exhibited no phonemic learning were re-enrolled in an experimental treatment programme following a 2-month period of no intervention. The aim of treatment was to present not only the linguistic domains, but also the cyclic nature of the principle by introducing new phonemic distinctions sequentially. In keeping with the initial experimental study of Laryngeal-Supralaryngeal Cyclicity, one child (Subject 4) received treatment consistent with the cycle, being exposed to alternating laryngeal and supralaryngeal distinctions. The other child (Subject 2) was exposed to the cycle in a way that was comparable to teaching out-of-phase, namely consecutive supralaryngeal distinctions were presented. Consistent with the earlier findings, and in accord with the principle, it was predicted that the child taught consecutive supralaryngeal distinctions out-of-phase would fill-in missing laryngeal distinctions, thereby completing more phases of the cycle than that child taught in-phase who was likely to evidence only treated phases of the cycle. Alternatively, if these children did not expand their phonemic repertoires following a second phase of intensive intervention, then this truly would be cause for considering them to be at risk, and the contributing factors associated with this would need to be systematically explored.

Background to subjects and phonemic inventories

Subjects 4 and 2 were 3;11 and 5;2 (years;months) respectively at the time of enrolment in the previous Gierut (1994b) study. Both children met the entry criteria for participation, including age-appropriate performance on tests of intelligence (Levine, 1986) and expressive and receptive language (Dunn and Dunn, 1981; Hresko, Reid and Hammill, 1981; Newcomer and Hammill, 1988); normal hearing (ASHA, 1985) and oral-speech motor abilities (Robbins and Klee, 1987); and residence in a monolingual English-speaking home. With regard to the phonological systems the children exhibited reduced consonantal inventories, scoring below the first percentile and producing a minimum of 11 sounds in error across three different sound classes on the *Goldman-Fristoe Test of Articulation* (Goldman and Fristoe, 1986).

Detailed phonological analyses were developed from extended samples of spontaneous speech and citation forms (Gierut, 1985). The primary focus was on the phonemic inventories and the target phonemes excluded by phonotactic constraints. Using criteria established in the literature (Gierut *et al.*, 1994; cf. Cook, 1988), a sound was assigned phonemic status if it was used contrastively in two unique sets of true minimal pairs. Minimal pairs were identified independent of the ambient sound system. The phonemic

inventories of each child prior to treatment are reported in Table 1.

In accord with experimental manipulations, the properties of the system were controlled for laryngeal or supralaryngeal distinction as contrastive. Both children also reported in Table 1. Both children had their phonemic inventories and the nature of the laryngeal distinction in treatment of /s/. Prior to treatment of /s/, and for Subject 4, obstruents were neither child exhibited any unusual phonological systems of 4 months, but neither child showed evidence of (Table 1). Children then entered treatment in the present study. Subjects 4 and 2 had the phonological systems of both children.

Experimental design

A staggered multiple-baseline multiple-probe design (McReynolds, 1980) was used. In the baseline, children were exposed to a single sound administered to Subject 4 and Subject 2. The design incorporated additional baseline probes for each sound. These are conventionally used to establish a true baseline appears to be characteristic of the sound and the programme advances to treatment of the sound. This can be structured as series of consecutive probes on a given sound in the treated condition. This design feature was especially useful for the experimental manipulations.

Independent variables

As in the previous Gierut (1994b) study, the cycle were manipulated. However, the cycle was presented sequentially rather than singly. The cycle distinction—laryngeal or supralaryngeal—was presented with four consecutive distinctions in a series of alternating laryngeal and supralaryngeal distinctions. The child taught consecutive supralaryngeal distinctions in alternation exposed Subject 4 to two complete cycles in-phase. The child taught consecutive laryngeal distinctions also introduced a cycle, but the cycle was consistently omitted in treatment.

The specific target sounds for treatment were selected from among the phonemic inventories of the children (Table 1). Treated sounds were always exposed in a 0% baseline and true baseline condition. This was crucial to this experimental test.

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inventories of each child prior to the initiation of treatment in the earlier study are shown in Table 1.

In accord with experimental manipulations of the Gierut (1994b) study, only redundant properties of the system were considered for treatment in order to introduce a new laryngeal or supralaryngeal distinction as contrastive. The redundant properties of each child's system are also reported in Table 1. Both children were treated in-phase given the composition of their phonemic inventories and the experimental assignments. Subject 4 was presented with a laryngeal distinction in treatment of /f/, and Subject 2 a supralaryngeal distinction in treatment of /s/. Prior to treatment, for Subject 4, labial continuants were predictably voiced, and for Subject 4, obstruents were predictably non-continuant. In the course of treatment neither child exhibited any unusual learning patterns. Treatment lasted the average duration of 4 months, but neither child showed any improvements or change in the phonemic system (Table 1). Children then entered a 2-month period of no-treatment before being re-enrolled in the present study. Subjects 4 and 2 returned at ages 4;5 and 5;8 respectively. At that time the phonological systems of both children remained the same.

Experimental design

A staggered multiple-baseline across subjects was used in combination with a multiple-probe design (McReynolds and Kearns, 1983). Consistent with the multiple-baseline, children were exposed to a baseline period followed by treatment, with two baselines administered to Subject 4 and three baselines to Subject 2. The multiple-probe design incorporated additional baseline periods administered just prior to treatment of a given sound. These are conventionally known as *true baselines*. In the multiple-probe design, if a true baseline appears to be changing in any way, then that phase of treatment is skipped and the programme advances to the next target. Thus, a phonological treatment programme can be structured as series of consecutive and sequential targets, and the impact of treatment on a given sound in the treated series can be examined relative to all subsequent sounds. This design feature was especially well suited to the present study given the intended experimental manipulations.

Independent variables

As in the previous Gierut (1994b) study, both the linguistic domain and the phase of the cycle were manipulated. However, in the present study the cyclic phase was presented sequentially rather than singly. That is, rather than being exposed to a single distinction—laryngeal or supralaryngeal—in a given phase, the children were each presented with four consecutive distinctions in treatment. In particular, Subject 4 was taught a series of alternating laryngeal and supralaryngeal distinctions, whereas Subject 2 was taught consecutive supralaryngeal distinctions. Teaching laryngeal–supralaryngeal distinctions in alternation exposed Subject 4 to the cyclic nature of the principle by introducing two complete cycles in-phase. Teaching consecutive supralaryngeal distinctions to Subject 2 also introduced a cycle, but it was out-of-phase because the laryngeal domain was consistently omitted in treatment.

The specific target sounds for treatment were intended to illustrate these distinctions, and were selected from among the redundant properties of each child's sound system (Table 1). Treated sounds were always excluded from the phonemic repertoire and produced with 0% baseline and true baseline accuracy. The actual sounds selected for treatment were not crucial to this experimental test of cyclicity because the principle is formulated with

Table 1. For each subject the pretreatment phonemic inventory and redundancies, the treated phases and phonemes in each of the two experimental studies, and the longitudinal course of phonemic acquisition characterized as laryngeal and supralaryngeal properties

Subject	Pretreatment phonemic system		Treated phases and phonemes		Acquisition course					
	Inventory	Redundancies	Singly (Gierut, 1994b)	Sequentially (Gierut and Morrisette, 1995)	L	SL	L	SL	L	SL
4	m nŋ pb td kg v	Continuants = voiced and labial Obstruents = non-contour Sonorants = nasal	L f	L SL L SL f z s ɔ		f s z				
	m n ŋ pb td kg l	Obstruents = non-continuant and noncontour Non-nasal sonorants = lateral	s	SL SL SL SL s f θ ʃ		z s s f		θ ʃ		

subsegmental properties in min both children to nearly the sa experimental assignments. For sequence was the phoneme ta phonemes representing each of each child.

More specifically, the treatr distinction in contrast to /v/, wh accord with the experimental m presented next through treatmen and coronal fricatives. A laryng presentation of /s/ as the voicele supralaryngeal distinction inv comparison, Subject 2 began tre within obstruents. Then /f/ was place contrast between labial a thereby introducing stridency as fourth consecutive supralaryng anteriority) within coronal frica

Treated sounds were tau permissible nonsense words (Gierut, 1992). The treatment the type and duration of inte (1994b) study; but here it wa limited to a single sound. This v of Laryngeal-Supralaryngeal C of the children's learning patte times weekly. Treatment proceed of each targeted sound. Pre-e used to determine when treatr Mastery was not a requireme treated sound a child remaine sound production in NSW item ever occurred first. The spon 80% accurate over two cor were completed, whichever cam in the Appendix.

Dependent variable

Consistent with the previous G child's phonemic inventory was of treated and untreated target phonemic inventory. Sounds picture-naming task (Gierut, 1 schedule of two sessions, with administrations generally corre continued to 1 month post-treat

subsegmental properties in mind. This notwithstanding, an effort was made to introduce both children to nearly the same sounds in treatment, but also in keeping with their experimental assignments. For both children the first sound introduced in the treatment sequence was the phoneme taught in the previous Gierut (1994b) study. The treated phonemes representing each of the four distinctions in the cycle are shown in Table 1 for each child.

More specifically, the treatment sequence for Subject 4 began with /f/ as a laryngeal distinction in contrast to /v/, which was already functioning in the phonemic repertoire. In accord with the experimental manipulation for this child, a supralaryngeal distinction was presented next through treatment of /z/, introducing a place contrast among voiced labial and coronal fricatives. A laryngeal distinction was then treated in the sequence through presentation of /s/ as the voiceless coronal counterpart to /z/. Treatment concluded with a supralaryngeal distinction involving stridency through the presentation of /θ/. In comparison, Subject 2 began treatment with /s/ as a supralaryngeal continuancy distinction within obstruents. Then /f/ was presented as another supralaryngeal distinction, namely a place contrast between labial and coronal fricatives. The next treatment target was /θ/, thereby introducing stridency as a third supralaryngeal distinction. /ʃ/ was presented as the fourth consecutive supralaryngeal distinction in an effort to further elaborate place (i.e. anteriority) within coronal fricatives.

Treated sounds were taught in the word-initial position of phonotactically permissible nonsense words (NSWs) using an established story-telling paradigm (Gierut, 1992). The treatment itself was structured to parallel as closely as possible the type and duration of intervention that was provided during the earlier Gierut (1994b) study; but here it was spread across four treated sounds instead of being limited to a single sound. This was done to ensure similarities across the two experiments of Laryngeal-Supralaryngeal Cyclicity for comparison of findings and interpretation of the children's learning patterns. Treatment was delivered in 60-min sessions three times weekly. Treatment proceeded through imitative and spontaneous phases of production of each targeted sound. Pre-established time- and performance-based criteria were used to determine when treatment should advance to sequential sounds in the cycle. Mastery was not a requirement for progression through the sequence. For a given treated sound a child remained in the imitative phase until achieving 65% accurate sound production in NSW items, or until two treatment sessions were completed, whichever occurred first. The spontaneous phase continued until sound production was 80% accurate over two consecutive sessions, or until four treatment sessions were completed, whichever came first. The step-by-step treatment programme is provided in the Appendix.

Dependent variable

Consistent with the previous Gierut (1994b) study, change in the composition of each child's phonemic inventory was the dependent measure. Change was evaluated on probes of treated and untreated target English sounds that were excluded from each child's phonemic inventory. Sounds were sampled in real words using a spontaneous picture-naming task (Gierut, 1985). Probes were administered on a variable interval schedule of two sessions, with an average of 11 samples obtained for each child. Probe administrations generally corresponded to programme advancements (Appendix) and continued to 1 month post-treatment for each child.

It should be noted that a child's day-to-day productions during treatment were not evaluated in studies of Laryngeal-Supralaryngeal Cyclicity (e.g. treatment as a reflection of performance). Instead, the central research question involved whether or not a child would acquire and internalize the phonological information presented in treatment as part of the phonemic system (e.g. generalization as a reflection of linguistic competence). For this reason, when evaluating change in each child's phonemic inventory, both qualitative and quantitative probe data were taken into account (Gierut, 1994a,b). Qualitatively, a sound was taken to be phonemic if two unique sets of true minimal pairs were identified at a given point in time, and then again at each of the subsequent samplings. As above, the qualitative assessment of phonemic status was based on the child's contrastive use of sounds, irrespective of the ambient phonology. Quantitatively, a sound was assigned phonemic status if it was also produced with a minimum of 6% probe accuracy relative to the target phonology. Both qualitative and quantitative conditions had to obtain conjunctively. In this way, then, establishing the phonemic status of sounds in a child's inventory incorporated both independent and relational considerations. This was also a rather conservative estimate of the phonemic system because a minimal degree of consistency and accuracy was required, and potential variation and reversals often reported in the development literature could be set aside.

From the qualitative and quantitative determination of the phonemic inventory across time it was thus possible to plot a sequence of acquisition for each child. The sequence reflected the order of emergent phonemic distinctions in a child's sound system, based qualitatively on when contrasts were first observed, and supported quantitatively by increasingly accurate productions. These sequences of phonemic acquisition were the primary evidence used in evaluation of the children's learning patterns relative to the principle of Laryngeal-Supralaryngeal Cyclicity.

Reliability

Inter-judge transcription reliability was calculated on 60% of all probes administered. The second author (M.L.M.) and a trained judge (J.T.), blind to the purpose of the study, phonetically transcribed each child's whole-word responses on randomly selected probes. From these randomly selected probes, 5533 consonants were independently transcribed using narrow notation of the IPA, and compared point-to-point. Consonant transcription agreement ranged from 86% to 96%, with a mean of 92%. Only 10 of the 5533 consonants transcribed (i.e. 0.002%) involved relevant differences between the judges' transcriptions and their indication of whether phonemes excluded from the inventory were correct or incorrect relative to the ambient target.

Results and discussion

The longitudinal courses of phonemic acquisition for the two children of this study are examined relative to the principle of Laryngeal-Supralaryngeal Cyclicity in general, and the sequential manipulations of the cyclic nature of this principle in clinical treatment in particular. The individual learning patterns of each child are presented with consideration of qualitative and quantitative changes in the phonemic inventory. Recall that the status of the phonemic inventory was established on the conjunction of qualitative conditions (i.e. true minimal pairs) and quantitative conditions (i.e. minimum 6% probe accuracy). Table 1 reports the qualitative changes as a longitudinal acquisition course tracing the order of

Figure 2. Quantitative acquisition as percentages of mean probe accuracy. The specific phonemes introduced in 1. For Subject 2, in the final supralaryngeal phase (circle) are shown. Baseline performance is shown.

emergent phonemes for each child. The results are presented quantitatively as mean percentages of probe accuracy. Figure 3 shows the percentages of probe accuracy in time. The results across children for Laryngeal-Supralaryngeal Cyclicity are discussed.

Figure 3. Percentages of probe accuracy for Subjects 2 and 4. Phonemes added during supralaryngeal phase are shown.

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Figure 2. Quantitative acquisition curves for Subjects 2 and 4. Cyclicity is plotted longitudinally as percentages of mean probe accuracy with alternations of laryngeal and supralaryngeal phases. The specific phonemes introduced in each phase of the cycle for each child are reported in Table 1. For Subject 2, in the final supralaryngeal phase, accuracy of both /θ/ (filled circle) and /ʃ/ (shaded circle) are shown. Baseline performance for both children was 0% accuracy.

emergent phonemes for each child. Figure 2 plots these same longitudinal changes quantitatively as mean percentages of accurate sound production as measured on the probes. Figure 3 shows the percentages of accurate sound production at the final sampling point in time. The results across children are compared, and the implications of these findings for Laryngeal-Supralaryngeal Cyclicity as a broad principle of phonological acquisition are discussed.

Figure 3. Percentages of probe accuracy at 1 month post-treatment for each phoneme acquired by Subjects 2 and 4. Phonemes added during laryngeal phases of the cycle are indicated by shaded bars; those added during supralaryngeal phases are open.

*Phonemic learning patterns**Subject 4*

As one manipulation of Laryngeal–Supralaryngeal Cyclicity, Subject 4 was exposed to the alternating laryngeal and supralaryngeal treatment targets /f z s ð/, presented in that order. In treatment of NSW items this child typically followed the pre-established time-based criteria, completing two sessions in the imitative and four in the spontaneous phase of production. For all four treated sounds, production in the NSW items ranged from 63% to 93% accuracy, demonstrating that the child achieved a degree of ambient-like sound production during treatment.

Change in the overall composition of Subject 4's phonemic repertoire was observed, but new phonemes were not added until after three of the four targeted sounds were taught. Moreover, the newly added phonemes were used with no more than 35% target-accuracy, as reflected quantitatively in production of untreated words sampled at the 1-month post-treatment point (Figure 3). As reported in Table 1 and Figure 2, the first new phoneme to emerge for Subject 4 was /f/, followed by /s/, followed by /z/. The addition of /f/ was indicative of a laryngeal distinction among labial continuants, introducing a contrast between /v/–/f/. The phonemic use of /s/ signalled next a supralaryngeal place distinction among continuants, achieving a distinction between labial and coronal fricatives. Finally, the introduction of /z/ represented a laryngeal distinction, with voice becoming a contrastive property of coronal fricatives.

From these data it seems that the order of phonemic acquisition by Subject 4 was wholly compatible with the principle of Laryngeal–Supralaryngeal Cyclicity. Alternations among laryngeal and supralaryngeal properties of the system were observed, with the child adding three new phonemes to his repertoire, and completing three phases of the cycle. Interestingly, only sounds that were taught gained phonemic status in Subject 4's system, but this did not extend to all treated targets. In particular, although the child was exposed to and produced /ð/ in clinical treatment of the NSW items, this segment was never incorporated into the phonemic repertoire even at 1 month post-treatment.

It is also relevant that the order of phonemic acquisition by Subject 4 was not in 1 : 1 correspondence with the treated targets. That is, /z/ was introduced in treatment as a supralaryngeal distinction, whereas /s/ was intended as a laryngeal distinction. However, Subject 4 acquired /s/ as the supralaryngeal distinction and /z/ as the laryngeal distinction. Here, the child acquired the expected distinctions, but not the intended sounds, in the order predicted from the principle. This finding is consistent with previous studies of Laryngeal–Supralaryngeal Cyclicity (Gierut, 1994a,b), and underscores the importance of the subsegmental nature of this principle. From the principle it is not specific sounds *per se* that are central to phonemic acquisition, but rather the emergence of specific types of distinctions. It also underscores the seemingly unpredictable way that treatment and learning interact.

Subject 2

The experimental treatment sequence for Subject 2 introduced consecutive supralaryngeal distinctions presented in the order /s f θ ʃ/. During treatment of target sounds the child met the time-based criteria in imitative and spontaneous phases of production. Treated sound production in the NSW items was in the range of 77–95% accuracy, again demonstrating improvements in performance during treatment.

Like Subject 4, this child exhibited changes in his phonemic repertoire, but these were delayed relative to treatment. Expansion of the phonemic inventory was first observed

immediately post-treatment. However, untreated segments to the phonemic repertoire were 70–100% target-accuracy as measured. In particular, Subject 2 added six new phonemes to his repertoire in the first cycle. Table 1 and Figure 2 show the order of a supralaryngeal manner distinction among non-continuant obstruents. Prior to treatment, /θ/ was a non-continuant. Next to emerge was /ʃ/, a coronal non-continuant. Following this was the acquisition of /s/, a labial and coronal continuant. /f/ emerged next, a coronal continuant. Finally, /θ ʃ/ emerged as a coronal continuant series. With /θ/ a strident, and with /ʃ/, strident coronal. The simultaneous emergence of /s/ and /f/ first occurred phonetically in the same sample, and were produced more than one sound was added. This was as two consecutive phases of the cycle (principle) for at least two reasons. First, in a given phase is not peculiar to Subject 2 and supported by similar types of data. Second, a phase of the cycle must be established before the way as the determination of cyclicity (cf. Kiparsky, 1982). In the absence of Subject 2 acquired both /θ ʃ/ and /s f/ a phase of the cycle.

The cyclic alternation of laryngeal and supralaryngeal distinctions in the phonemic learning pattern was observed in Subject 2. In the supralaryngeal distinctions, the principle. Subject 2 not only added new phonemes to his repertoire. As with the previous subjects, the presentation of treated sounds in the phonemic repertoire emerged, but not in the intended as illustrative of one child as another type based on the case in the acquisition of /s/, a laryngeal distinction. These findings support the principle, and the fact that children may be, children often acquire phonemic differences.

Comparison across subjects

Comparison of the phonemic repertoires across the children, followed the cyclic alternation of laryngeal and supralaryngeal distinctions across children.

Subject 4 was exposed to the /θ/, presented in that order. Pre-established time-based phases of the spontaneous phase of items ranged from 63% to 100% of ambient-like sound

phonemic repertoire was observed, targeted sounds were taught. More than 35% target-accuracy, sampled at the 1-month post-treatment. In Subject 2, the first new phoneme was /z/. The addition of /f/ was targeted, introducing a contrast in laryngeal place distinction among coronal fricatives. Finally, /v/ became a contrastive

by Subject 4 was wholly cyclical. Alternations among segments, with the child adding new phases of the cycle. Status in Subject 4's system, though the child was exposed to this segment was never post-treatment.

Subject 4 was not in 1:1 ratio produced in treatment as a laryngeal distinction. However, as the laryngeal distinction. Targeted sounds, in the order of presentation with previous studies underscores the importance of the order of specific types of sounds that treatment and

consecutive supralaryngeal target sounds the child met with production. Treated sound accuracy, again demonstrating

repertoire, but these were not the first observed

immediately post-treatment. However, unlike Subject 4, this child added both treated and untreated segments to the phonemic system. Moreover, he used newly added phonemes with 70–100% target-accuracy as measured quantitatively 1 month post-treatment (Figure 3). In particular, Subject 2 added six new phonemes to his repertoire, completing five phases of the cycle. Table 1 and Figure 2 show that the first phoneme to emerge was /z/, indicative of a supralaryngeal manner distinction involving a contrast among continuant and non-continuant obstruents. Prior to this, the only obstruents in the system were predictably non-continuant. Next to emerge was /s/ as a laryngeal distinction within the continuants. Following this was the acquisition of /f/, introducing a supralaryngeal place contrast among labial and coronal continuants. /v/ was then acquired as a laryngeal distinction among labial continuants. Finally, /θ/ emerged simultaneously as supralaryngeal distinctions within the coronal continuant series. With /θ/, coronal fricatives were distinctively non-strident and strident, and with /ʃ/, strident coronal fricatives were distinctively non-anterior and anterior. The simultaneous emergence of these segments was supported by the fact that /θ/ and /ʃ/ first occurred phonetically in the same sample, were used phonemically in minimal pairs in the same sample, and were produced with the same percentage of mean accuracy. That more than one sound was added during a given phase of the cycle should not be interpreted as two consecutive phases of the same type (and therefore a violation of the cyclicity principle) for at least two reasons. First, the pattern of acquiring more than one phoneme in a given phase is not peculiar to this subject, having been documented in other studies and supported by similar types of data (Gierut, 1992a). Second, the completion of a given phase of the cycle must be established on independent empirical grounds, in much the same way as the determination of cyclic rule application in lexical phonology (Gierut, 1992a; cf. Kiparsky, 1982). In the absence of evidence to the contrary, it can only be surmised that Subject 2 acquired both /θ/ and /ʃ/ at the same time, and as representative of a supralaryngeal phase of the cycle.

The cyclic alternation of laryngeal and supralaryngeal distinctions was again observed in the phonemic learning patterns of Subject 2. Despite being taught consecutive supralaryngeal distinctions, the course of acquisition proceeded as predicted by the principle. Subject 2 not only acquired each of the treated phonemes, but also added untreated phonemes to his repertoire, thereby filling-in the expected laryngeal distinctions. As with the previous subject, this child did not adhere directly to the order of presentation of treated sounds in the acquisition of phonemic distinctions. That is, treated phonemes emerged, but not in the order taught. Moreover, treated phonemes were intended as illustrative of one kind of distinction, but instead were internalized by the child as another type based on his progression through the cycle. This was specifically the case in the acquisition of /s/, intended as a supralaryngeal distinction but learned as a laryngeal distinction. These findings again highlight the subsegmental characteristics of the principle, and the fact that, no matter what a clinician's expressed treatment goals may be, children often acquire the linguistic system uniquely with apparent individual differences.

Comparison across subjects

Comparison of the phonemic learning patterns revealed qualitative and quantitative differences across the children, despite the fact that expansion of the phonemic repertoire followed the cyclic alternation of laryngeal and supralaryngeal distinctions for both children.

of the cycle in treatment. In did not add other untreated ie sequential presentation of n contrast, Subject 2 learned ases of the cycle that were consecutive supralaryngeal npleted more phases of the n received the same amount

ic learning that took place. ie cycle directly resulted in eatment for Subject 4, as in bject 2, taught out-of-phase nds, treatment that involved of the same type seemed to

n were consistent with the laryngeal Cyclicity (Gierut, f the cycle was manipulated l). Children taught in-phase associated with the treated y Subject 4. Children taught ling the cycle to untreated manipulations in this study f a single phase of the cycle ase relationship, rather than ic acquisition.

Laryngeal-Supralaryngeal ly did not benefit from the cycle. For these children, onstration of the recursive ace using this alternate and this study were not at risk, 994b) treatment study. The y be related to the type of s study.

several means of triggering ation. Drawing from both ie phonemic inventory may ourse preliminary, and are icture involves explicitly l phases of the cycle, as in esents a given phase of the child to also elaborate the untreated, as for Subject 2.

A third possibility introduces one and only one linguistic dimension of the cycle, but the phase relationship of this property is out-of-phase, as in the initial study.

What is common across the three treatment structures is that each provides the child with an opportunity to be exposed to and to test linguistic cyclicity. Cyclicity in treatment may be presented more or less explicitly, depending on whether a child is presented with the cycle directly or whether the relevant phases of the cycle must be discovered through generalization to untreated segments. The extent of phonemic expansion following exposure to these treatment structures may also vary. Based on the outcomes of these studies, one hypothesis is that teaching distinctions out-of-phase (either singly or sequentially) will result in more extensive phonemic learning than teaching distinctions (singly or sequentially) in-phase. This hypothesis serves to motivate studies of relative treatment efficacy in manipulations of Laryngeal-Supralaryngeal Cyclicity.

Cyclicity as a principle of phonemic acquisition

Collectively, these findings provide a backdrop for continued study of a number of other issues central to phonological theory and acquisition. Specifically, Laryngeal-Supralaryngeal Cyclicity is a linguistic principle of the acquisition of subsegmental structure. While it appears to be descriptively and psycholinguistically relevant, it defines only one aspect of the phonology and its acquisition, namely consonantal contrasts. There may also be other cyclic principles of language acquisition. The substantive domains of these alternate proposals will probably differ for different aspects of the phonology, as in the acquisition of vowels as opposed to consonants. Yet what may remain constant across linguistic principles is their bivalent and cyclic nature. For example, in the acquisition of vowels there has already been a suggestion that a cycle operates, but between properties of height and depth (Gierut, 1994a). As another example, with regard to phonotactics, there may be cyclicity between the segmental and skeletal tiers of the representation. Perhaps, then, cyclicity not only defines a given level, but extends beyond and integrates multiple components of the phonological representation. The identification of the relevant domains of each cycle and the interactions between cycles will probably contribute to a broad understanding of the basic structure and organization of phonological representations.

The cyclic nature of linguistic principles may figure into human development more generally. Within a dynamic systems framework, cyclicity has been cited as a pattern of development underlying the emergence of diverse motoric and cognitive abilities (Smith and Thelen, 1993). From a similar theoretical perspective, Mohanan (1993) has advanced that cyclicity defines the emergence of complexity in phonological development. Thus, it may be that the cyclic aspect of linguistic principles may derive from cognition, given its reportedly broad applicability, whereas the substantive properties of the principles (e.g. laryngeal-supralaryngeal, or height-depth) originate obviously from language. When put to further test these hypotheses and observations may lead to a better understanding of the relationships between cognition and language.

Finally, Laryngeal-Supralaryngeal Cyclicity may provide an initial explanation for the apparent discrepancies observed in the teaching versus learning of language. At present the details of linguistic learning seem largely unpredictable, with no guarantee that what a child is taught will be learned, or for the reasons intended. However, by adopting a principle such as Laryngeal-Supralaryngeal Cyclicity, it should be possible to plot a course of phonemic acquisition by considering a child's grammar at a given point in time relative to the principle

and treatment. For a given child, treatment may serve to trigger the cyclic principle. The subsegmental properties of phonemic elaboration to emerge in treatment may be projected from the principle, independent of the sounds that may be taught. Variation in learning for a given child may relate to the underdetermined nature of the principle, with specific segments emerging to the exclusion of others. Individual differences in learning across children may be traceable to the way in which treatment capitalizes on, or enhances the fundamental properties and structure of the principle. Ultimately, through a principle approach to the study of language acquisition (cf. Chomsky, 1981), it may be possible to identify the independent and universal mechanisms that guide the developing linguistic system to its end-state.

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References

- ARCHANGELI, D. (1988) Aspects of underspecification theory. *Phonology*, **5**, 183–207.
- ASHA COMMITTEE ON AUDIOLOGIC EVALUATION (1985) Guidelines for identification audiometry. *ASHA*, **27**, 49–52.
- CHOMSKY, N. (1981) *Lectures on Government and Binding* (Dordrecht: Foris).
- CLEMENTS, G. N. (1985) The geometry of phonological features. *Phonology*, **2**, 225–252.
- CLEMENTS, G. N. (1987) Phonological feature representation and the description of intrusive stops. *Chicago Linguistic Society*, **23**, 29–50.
- COOK, V. J. (1988) *Chomsky's Universal Grammar* (New York: Basil Blackwell).
- COSTELLO, J. and ONSTINE, J. (1976) The modification of multiple articulation errors based on distinctive feature theory. *Journal of Speech and Hearing Disorders*, **41**, 199–215.
- DINNSSEN, D. A. and ELBERT, M. (1984) On the relationship between phonology and learning. In M. Elbert, D. A. Dinnsen and G. Weismer (Eds), *Phonological Theory and the Misarticulating Child* (ASHA Monographs No. 22) (Rockville, MD: ASHA).
- DINNSSEN, D. A., CHIN, S. B., ELBERT, M. and POWELL, T. W. (1990) Some constraints on functionally disordered phonologies: phonetic inventories and phonotactics. *Journal of Speech and Hearing Research*, **33**, 28–37.
- DUNN L. M. and DUNN, L. M. (1981) *Peabody Picture Vocabulary Test-Revised* (Circle Pines, MN: American Guidance Service).
- ELBERT, M., DINNSSEN, D. A. and POWELL, T. W. (1984) On the prediction of phonologic generalization learning patterns. *Journal of Speech and Hearing Disorders*, **49**, 309–317.
- ELBERT, M., POWELL, T. W. and SWARTZLANDER, P. (1991) Toward a technology of generalization: how many exemplars are sufficient? *Journal of Speech and Hearing Research*, **34**, 81–87.
- FEY, M. E. and STALKER, C. H. (1986) A hypothesis-testing approach to treatment of a child with an idiosyncratic morphophonological system. *Journal of Speech and Hearing Disorders*, **51**, 324–336.
- FORREST, K., WEISMER, G., HODGE, M., DINNSSEN, D. A. and ELBERT, M. (1990) Statistical analysis of word-initial /k/ and /t/ produced by normal and phonologically disordered children. *Clinical Linguistics and Phonetics*, **4**, 327–340.
- GIERUT, J. A. (1985) *On the relation of learning in misarticulating Club*.
- GIERUT, J. A. (1992) The condition of Speech and Hearing Research.
- GIERUT, J. A. (1994a) Cyclicity 1–23.
- GIERUT, J. A. (1994b) An experimental publication.
- GIERUT, J. A., ELBERT, M. and DINNSSEN, D. A. (1990) Generalization learning. *Research*, **30**, 462–479.
- GIERUT, J. A., SIMMERMAN, C. L. and DINNSSEN, D. A. (1990) Phonological systems. *Journal of Speech and Hearing Research*, **33**, 1–10.
- GOLDMAN, R. and FRISTOE, M. (1990) American Guidance Service.
- HRESKO, W. P., REID, D. K. and HARRIS, J. (1980) (Austin, TX: Pro-Ed.).
- KIPARSKY, P. (1982) Lexical morphology in the Morning Calm (Seoul: Seoul National University Press).
- LEONARD, L. B. and BROWN, B. L. (1982) A study of an unusual phonological disorder. *Journal of Speech and Hearing Disorders*, **49**, 41–50.
- LEVINE, M. N. (1986) *Leiter International Test of Hearing* (Stoelting).
- MCREYNOLDS, L. V. and BENNETT, S. (1985) *Journal of Speech and Hearing Disorders*, **50**, 1–10.
- MCREYNOLDS, L. V. and KEARNS, L. (1985) *Communicative Disorders* (Stoelting).
- MOHANAN, K. P. (1993) Emergence of L. Menn and C. Stoel-Gammon. *Implications* (Timonium, MD: York Press).
- NEWCOMER, P. L. and HAMMILL, D. R. (1980) (TX: Pro-Ed.).
- POWELL, T. W. and ELBERT, M. (1984) later-developing consonants. *Journal of Speech and Hearing Disorders*, **49**, 211–218.
- POWELL, T. W., ELBERT, M. and DINNSSEN, D. A. (1984) generalization of misarticulation. *Research*, **34**, 1318–1328.
- ROBBINS, J. and KLEE, T. (1987) Children. *Journal of Speech and Hearing Disorders*, **52**, 1–10.
- ROCKMAN, B. K. and ELBERT, M. (1984) child. *Journal of Speech and Hearing Disorders*, **49**, 1–10.
- SABEN, C. B. and COSTELLO INGHAM, J. (1984) speech-sound production of children. *Hearing Research*, **34**, 102–110.
- SMITH, L. B. and THELEN, E. (1993) (Cambridge, MA: MIT Press).
- TYLER, A. A. and FIGURSKI, G. R. (1980) an implicational hierarchy. *Journal of Speech and Hearing Disorders*, **45**, 1–10.
- TYLER, A. A., EDWARDS, M. L. and FIGURSKI, G. R. (1980) knowledge and its relations. *Journal of Speech and Hearing Disorders*, **45**, 251–261.
- WEINER, F. F. (1981) Treatment of minimal contrast: two cases. *Journal of Speech and Hearing Disorders*, **46**, 97–103.

the cyclic principle. The treatment may be projected. Variation in learning for the principle, with specific differences in learning across children, or enhances the ability, through a principle (1981), it may be possible to use the developing linguistic

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ogy, 5, 183-207.

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it: Foris).

nology, 2, 225-252.

description of intrusive stops.

l Blackwell).

articulation errors based on disorders, 41, 199-215.

phonology and learning. In M. theory and the Misarticulating

the constraints on functionally ics. *Journal of Speech and*

-Revised (Circle Pines, MN:

of phonologic generalization 49, 309-317.

technology of generalization: earing Research, 34, 81-87.

to treatment of a child with i and Hearing Disorders, 51,

Al. (1990) Statistical analysis gically disordered children.

- GIERUT, J. A. (1985) *On the relationship between phonological knowledge and generalization learning in misarticulating children* (Doctoral dissertation, Indiana University Linguistics Club).
- GIERUT, J. A. (1992) The conditions and course of clinically-induced phonological change. *Journal of Speech and Hearing Research*, 35, 1049-1063.
- GIERUT, J. A. (1994a) Cyclicity in the acquisition of phonemic distinctions. *Lingua*, 94, 1-23.
- GIERUT, J. A. (1994b) An experimental test of phonemic cyclicity. (Manuscript submitted for publication.)
- GIERUT, J. A., ELBERT, M. and DINNSEN, D. A. (1987) A functional analysis of phonological knowledge and generalization learning in misarticulating children. *Journal of Speech and Hearing Research*, 30, 462-479.
- GIERUT, J. A., SIMMERMAN, C. L. and NEUMANN, H. J. (1994) Phonemic structures of delayed phonological systems. *Journal of Child Language*, 21, 291-316.
- GOLDMAN, R. and FRISTOE, M. (1986) *Goldman-Fristoe Test of Articulation*. (Circle Pines, MN: American Guidance Service.)
- HRESKO, W. P., REID, D. K. and HAMMILL, D. D. (1981) *The Test of Early Language Development* (Austin, TX: Pro-Ed.).
- KIPARSKY, P. (1982) Lexical morphology and phonology. In Linguistic Society of Korea, *Linguistics in the Morning Calm* (Seoul: Hanshin).
- LEONARD, L. B. and BROWN, B. L. (1984) Nature and boundaries of phonologic categories: a case study of an unusual phonologic pattern in a language-impaired child. *Journal of Speech and Hearing Disorders*, 49, 419-428.
- LEVINE, M. N. (1986) *Leiter International Performance Scale: A Handbook* (Chicago, IL: Stoelting).
- MCREYNOLDS, L. V. and BENNETT, S. (1972) Distinctive feature generalization in articulation training. *Journal of Speech and Hearing Disorders*, 37, 462-470.
- MCREYNOLDS, L. V. and KEARNS, K. P. (1983) *Single-subject Experimental Designs in Communicative Disorders* (Baltimore, MD: University Park Press).
- MOHANAN, K. P. (1993) Emergence of complexity in phonological development. In C. A. Ferguson, L. Menn and C. Stoel-Gammon (Eds), *Phonological Development: Models, Research, Implications* (Timonium, MD: York).
- NEWCOMER, P. L. and HAMMILL, D. D. (1988) *Test of Language Development-2 Primary* (Austin, TX: Pro-Ed.).
- POWELL, T. W. and ELBERT, M. (1984) Generalization following the remediation of early- and later-developing consonant clusters. *Journal of Speech and Hearing Disorders*, 49, 211-218.
- POWELL, T. W., ELBERT, M. and DINNSEN, D. A. (1991) Stimulability as a factor in the phonologic generalization of misarticulating preschool children. *Journal of Speech and Hearing Research*, 34, 1318-1328.
- ROBBINS, J. and KLEE, T. (1987) Clinical assessment of oropharyngeal motor development in young children. *Journal of Speech and Hearing Disorders*, 52, 271-277.
- ROCKMAN, B. K. and ELBERT, M. (1984) Untrained acquisition of /s/ in a phonologically disordered child. *Journal of Speech and Hearing Disorders*, 49, 246-253.
- SABEN, C. B. and COSTELLO INGHAM, J. (1991) The effects of minimal pairs treatment on the speech-sound production of two children with phonologic disorders. *Journal of Speech and Hearing Research*, 34, 1023-1040.
- SMITH, L. B. and THELEN, E. (1993) *A Dynamic Systems Approach to Development: Applications* (Cambridge, MA: MIT Press).
- TYLER, A. A. and FIGURSKI, G. R. (1994) Phonetic inventory changes after treating distinctions along an implicational hierarchy. *Clinical Linguistics and Phonetics*, 8, 91-108.
- TYLER, A. A., EDWARDS, M. L. and SAXMAN, J. H. (1990) Acoustic validation of phonological knowledge and its relationship to treatment. *Journal of Speech and Hearing Disorders*, 55, 251-261.
- WEINER, F. F. (1981) Treatment of phonological disability using the method of meaningful minimal contrast: two case studies. *Journal of Speech and Hearing Disorders*, 46, 97-103.

Appendix

Treatment sequence in the multiple-baseline multiple-probe design

Baseline the overall phonological system using the Phonological Knowledge Protocol (PKP: Gierut, 1985)

$n = 2$ administrations + 1 for each successive child in the multiple-baseline

Treated Sound 1†

True baseline: Probe using all PKP items that sample Sound 1

NSW baseline of Sound 1 and read corresponding NSW story

Imitation phase

Three trials per each of 15 NSW items ($n = 45$ trials)

Spontaneous phase

Reread corresponding NSW story

Four trials for each of 15 NSW items ($n = 60$ trials)

Probe changes in the phonology using PKP

Treated Sound 2

True baseline: Probe using all PKP items that sample Sound 2

NSW baseline of Sound 2 and read corresponding NSW story

Imitation phase

20 trials for each of five NSW items ($n = 100$ trials per session)

Continue to *Performance-based criterion*: 65% accuracy

OR

Time-based criterion: Completion of two treatment sessions, whichever should occur first

Spontaneous phase

Reread corresponding NSW story

20 trials for each of five NSW items ($n = 100$ trials per session)

Continue to *Performance-based criterion*:

80% accuracy over two consecutive sessions

OR

Time-based criterion: Completion of four treatment sessions, whichever should occur first

Probe changes in the phonology using PKP

Treated Sound 3: Repeat procedures as for Sound 2

Probe changes in the phonology using PKP

Treated Sound 4: Repeat procedures as for Sound 2

Probe changes in the phonology using PKP

Probe changes in the phonology at 2 weeks posttreatment using PKP‡

Probe changes in the phonology at 1 month posttreatment using PKP

†Recall that Sound 1 for both subjects was taught previously in the Gierut (1994b) study.

‡A 2-week post-treatment probe was not administered to Subject 4 because of the family's vacation.

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E. H. BUDE

Department of Speech
WA 98195, USA

R. D. KENT

Waisman Center, Un
USA

P. MILENK

Department of Elect
Wisconsin-Madison,

M. WORKIN

Marshfield Clinic, M

(Received 16 May 19

Abstract

A system for semi-automated analysis of speech, called FORMOFF, is described. Frequency, A = Amplitude, and duration are measured. Commercially available software is used to calculate instantaneous values, and a technique is developed with which to analyze the data. Issues are described. The applications: (1) segmental effects of a progressive neurological disorder, (2) acoustic study of production, (3) acoustic study of injury, and (4) phonetic assessment. Although the current technique promises several advantages, efficiency, parsimony, and accuracy are the primary analysis.

Keywords: acoustic analysis

Introduction

Background

It appears likely that progress in the treatment of speech and other speech disorders will