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Precursors to onset clusters in acquisition*

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ABSTRACT

Two lawful relationships involving word-initial onset clusters have been advanced in the acquisition literature; namely, that clusters imply affricates (Lleó & Prinz, 1996, 1997), and that liquid clusters imply a liquid distinction (Archibald, 1998). This study evaluated and extended the validity of these implicational laws in a population of 110 children (aged 3;0 to 8;6) with functional phonological delays who contributed extended speech samples for computational analyses. Results indicated that, for the most part, the composition of children's sound systems were in compliance with the proposed laws; however, there were noted asymmetries and apparent exceptions in the data. The asymmetries motivated an integration of the two laws to reveal a pattern of segmental–prosodic cyclicity consistent with deterministic models of phonological acquisition. The apparent exceptions highlighted the relevance of independent methodologies and offered a potential theoretical alternative with the Resolvability Principle as directions for future research.

INTRODUCTION

Children's acquisition of consonant clusters has received considerable attention from converging research perspectives. A primary emphasis has been the word-initial onset cluster, with three related issues guiding the general programme of study. One line of investigation focuses on children's production of clusters and their corresponding errored outputs (Chin & Dinnsen, 1992; Smit, 1993). The goals are to document developmental stages in a child's progression from production of 1- to 2-element consonantal sequences, and to capture the range of variation in cluster simplification relative to the adult target. Toward this end, acoustic and articulatory

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phonetic evidence have accrued in cross-sectional and longitudinal studies. Another line of research examines children's perception and conceptualization of clusters (Barton, Miller & Macken, 1980; Lance, Swanson & Peterson, 1997). The purpose is to gain insight into a child's knowledge and interpretation of the structure of clusters as consisting of either one or two segmental units. By removing possible production constraints on performance within this approach, it has been possible to sample children's views of clusters from linguistic and metalinguistic perspectives. Still other research documents children's learning as induced through experimental manipulations of clusters (Powell & Elbert, 1984; Gierut, 1999). This work offers unique insights because data are gathered in clinical treatment of children with functional phonological delays. This population of children experiences slowed phonological development in the absence of other concomitant linguistic, cognitive, motor, or social lags. Characteristically, these children have severely restricted consonantal inventories which expand in size, composition, and complexity only following direct clinical treatment. Treatment is administered as an experiment; in these cases, with manipulation of clusters as the independent variable and the monitoring of subsequent changes in the phonology as the dependent variable. With this approach, hypotheses emerging from cross-sectional and longitudinal studies of production and perception of clusters in normal acquisition have been experimentally validated by the learning patterns of children with phonological delays. Taken together, these three lines of investigation converge by integrating normal and delayed development, perception and production, linguistic and metalinguistic knowledge, cross-sectional and longitudinal studies, and descriptive and experimental results. The convergence of multiple sources of evidence holds potential for yielding a comprehensive account of cluster acquisition.

Recently, another approach to the study of cluster acquisition has been advanced and follows directly from the study of fully-developed languages. That is to identify lawful and potentially universal relationships between clusters and other properties of the sound system. Universals are a hallmark of human language that take two forms (Greenberg, 1978). Absolute laws specify requisite properties of language, e.g. 'all languages have vowels'; whereas implicational laws state that certain properties necessarily imply certain others, but not the reverse, e.g. 'fricatives imply stops, but not *vice versa*.' Implying properties are taken to be more marked than the implied and thought to be structurally more complex. Implicational laws capture typological differences among languages, while absolute laws hold uniformly, with some parameterization possible. Regardless of their form or extent of application, and with few exceptions, universals have no known physical, cognitive, or functional origin (Anderson, 1981). Nonetheless, they must be directly accommodated as axioms in any theory of language or its acquisition.

A lawfulness approach to cluster acquisition has broad potential. First, while universals have been advanced and tested for a host of phonological properties in acquisition (Ferguson, 1977; Macken & Ferguson, 1987), clusters have not been a focal point. A study of the lawful patterning of clusters thereby fills a gap in the acquisition literature. Second, implicational laws in particular provide a framework by which to document systematicities in development, while also allowing for individual differences in the acquisition of clusters (Dinnsen, 1992). Third, marked phonological properties are thought to be more difficult for children to acquire, with unmarked properties presumably emerging first (Gnanadesikan, 1996). Studies of implicational laws involving clusters may help identify the precursors to more complex linguistic structure. Fourth, markedness provides a recommended course of treatment for children with phonological delays. Namely, treatment of a marked property has been shown to trigger corresponding unmarked properties, thereby inducing greater learning (Dinnsen & Elbert, 1984). Finally, acquisition data may lend support to the universality of implicational relationships by demonstrating the strength and breadth of observed patterns (Ferguson, 1977). These considerations motivate the present study wherein we adopt a lawfulness approach to the acquisition of word-initial onset clusters. Two recently proposed implicational laws are evaluated: one derives from observations in first language acquisition and another from second language acquisition. Our test draws from children with functional phonological delays for a fully integrated perspective.

Markedness of clusters in first language acquisition

Lleó & Prinz (1996, 1997) monitored the longitudinal productions of consonant clusters by nine children, aged 1;5 to 2;2, learning either German or Spanish. Their aim was to establish a potential hierarchy of syllable complexity in typical development. Children's cluster productions were examined across word positions with attention to target language accuracy. That is, a relational analysis was used, with correspondence mappings between child outputs and intended adult target forms. Target clusters were operationalized as having two skeletal slots, i.e. one timing unit for each segment of the cluster. Consonant + glide sequences were included in the analysis despite some ambiguity about their cluster status (Davis & Hammond, 1995). The reason given was that children apparently do not handle these sequences differently from other clusters (Lleó & Prinz, 1996, 36). Fricative + obstruent stop sequences, which also have special cluster status (Clements, 1990), were excluded from the analysis. Conventional linguistic analyses assume that these sequences have only a single skeletal slot with an extrasyllabic first segment. Also, children have been shown to acquire fricative + obstruent stop sequences differently from other kinds of clusters (Gierut, 1999); consequently, these were set aside by Lleó & Prinz. Several general patterns involving clusters were observed in their cross-linguistic data. Syllable onsets emerged before codas; yet clusters in coda position emerged before those in onset position. Singletons emerged before clusters across contexts, including the more complex category of affricates which involve the conjunction of a stop-like followed by a fricative-like constriction in production. But, affricates in onset position emerged before those in coda position. From this, Lleó & Prinz traced a potential course of acquisition (independent of context) such that singletons were acquired before affricates which, in turn, were acquired before clusters. They further hypothesized that these may be lawfully related such that clusters imply affricates imply singletons. Predictably then, singletons and affricates are precursors to clusters. Theoretically, Lleó & Prinz attributed this lawful relationship to principles of sonority and hierarchical expansion of the structure of syllables. For onsets in particular (in keeping with the scope of our paper), they outlined a developmental progression from nonbranching onsets (singletons) to branching segments (affricates) to branching onsets (clusters), as depicted in Figure 1. The general supposition was that branching at the level of the

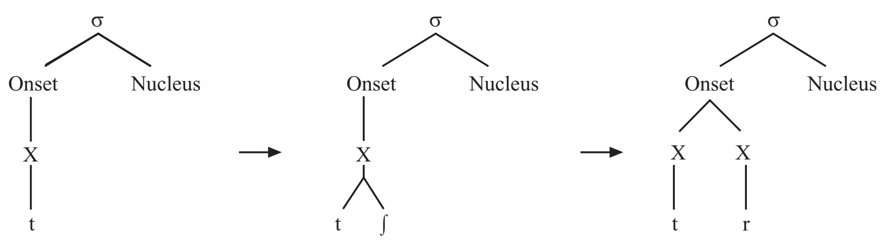

Fig. 1. Representation of syllable onsets with elaboration from singletons to affricates to true clusters. Only prenuclear structure is shown.

segment must be in place before branching is implemented at the level of the onset. Interestingly, while their data largely supported this proposal, there were language-specific differences among German and Spanish-speaking children associated with syllable assignment and the licensing of segments within each of these two languages.

Beyond the nine children of Lleó & Prinz's study, the lawful relationship among singletons, affricates, and clusters has received only preliminary attention in treatment studies of children with phonological delays (Gierut & Champion, 2001). Without exception, results showed that children spontaneously added affricates to the inventory following treatment of clusters. This supports the precursor status of branching segments to branching onsets as proposed, and is consistent with reports of the effects of markedness on learning. While these findings hold promise in validation of Lleó & Prinz's proposal, the evidence is indirect because treatment was not intended as an explicit manipulation of the law. Thus, it still must be determined whether the sound systems of children with phonological delays are in conformity with the patterning of affricates relative to clusters in the absence of clinical treatment.

Markedness of clusters in second language acquisition

Archibald (1998) evaluated adult second language learners' ability to produce onset clusters consisting of consonant + liquid sequences. At issue was the role of sonority relative to the complexity of segmental structure in the acquisition of clusters. Eight Korean learners of English generated speech samples that were analysed relationally with respect to target accuracy and coupled with supplementary acoustic analyses.

Findings indicated that learners produced consonant + liquid clusters, but only when they also maintained a phonemic distinction between the liquids /l/ and /r/. The presence of a liquid contrast was an especially relevant observation because, while the learners' native language of Korean included both liquids in the inventory, these functioned as allophones and not phonemes. Based on this, Archibald hypothesized that the occurrence of consonant + liquid clusters necessarily implies a liquid distinction, but not *vice versa*. Predictably, a phonemic contrast between /l/ and /r/ is a precursor to liquid clusters. Theoretically, Archibald suggested that this lawful relationship was due to an interaction between the hierarchical structure of segments and sonority, notably the same elements of Lleó & Prinz's account. He argued that when segments are contrastive, they contain greater representational (featural) structure than when they are not. Moreover, the amount of representational structure that a segment contains will determine whether or not it can 'govern' an adjacent segment. If one segment governs another, then the two may form a cluster; the sonority of syllables is thereby derived from segmental structure (cf. Rice, 1992). By this account, when second language learners acquire a contrast between /l/ and /r/, segmental structure is expanded sufficiently to allow for a governing relationship in the formation of consonant + liquid clusters.

In addition to data from second language acquisition, Archibald provided typological evidence from five fully-developed primary language families to validate his proposal that liquid clusters imply a liquid distinction. There were anomalies noted; however, these were largely traceable to language-specific differences in syllabification, again similar to the observations of Lleó & Prinz. With exception of brief consideration of the data from Amahl (Archibald, 1998, 208), Archibald's hypothesis has not been tested against the facts of first language acquisition, normal or delayed. As with the cluster–affricate law, it is not yet known whether the sound systems of children with phonological delays pattern in a manner consistent with the proposed cluster–liquid law.

Conformity to markedness

In general, an evaluation of an implicational law must consider four logical possibilities as potential occurrences in language, as shown in Table 1. Three of the four possibilities provide confirmatory evidence of lawfulness, whereas the fourth does not. Given the statement 'The occurrence of X implies Y, but not *vice versa*,' a language may present with (1) neither X nor Y (abbreviated hereafter as −X −Y); (2) not X but Y (−X +Y); (3) both X and Y (+X +Y); or (4) X but not Y (+X −Y). Of these, only the latter is in violation of markedness because the implying marked property occurs in the absence of the unmarked property. Stated another way, a complex phonological property would be present without also the simpler.

These logically possible manifestations of markedness can be specifically applied to the laws being considered herein (Table 1). Based on Lleó & Prinz, it is expected that children's inventories will include either no affricates and no clusters; affricates but not clusters; or affricates and clusters both. Cases of clusters in the absence of affricates should not be observed because affricates are the presumed precursors. Based on Archibald, it is predicted that children will present with either no liquid contrast and no consonant+liquid clusters; a liquid contrast but no consonant+liquid clusters; or both a liquid contrast and consonant+liquid clusters. Again, instances of consonant+liquid clusters without also a liquid distinction should not be found since a liquid contrast is the predicted precursor. A set of testable hypotheses about the composition of children's sound systems is thus delineated.

The purpose of this paper is to test these hypotheses in a large-scale archival study of children with functional phonological delays. Their production patterns are considered first with respect to the implicational relationships between clusters and affricates, and between clusters and liquids. Then, these two seemingly independent laws are examined from an integrated perspective to yield a unified markedness relationship. From this, it is possible to outline a potential developmental course in children's acquisition of clusters.

METHOD

Participants

Children who participated were 110 monolingual English-speakers with functional phonological delays. The children, 87 male and 23 female, were of the mean age 4;5, with the range being 3;0 to 8;6. Children were originally recruited by public announcement to participate in an ongoing experimental research programme on the learnability of sounds in clinical treatment (NIDCD 01694). As such, they were required to meet certain minimal entry

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TABLE 1. *Inventories and conformity to markedness*

Implicational laws and logically possible inventories			
X implies Y, but not *vice versa*	Clusters imply affricates	Consonant+liquid clusters imply a liquid contrast	Conformity?
−X −Y	No clusters and no affricates	No consonant+liquid clusters and no liquid contrast	Confirming evidence
−X +Y	No clusters but affricates	No consonant+liquid clusters but a liquid contrast	Confirming evidence
+X +Y	Clusters and affricates	Consonant+liquid clusters and a liquid contrast	Confirming evidence
+X −Y	Clusters but no affricates	Consonant+liquid clusters but no liquid contrast	Counterevidence

criteria including normal hearing, oral-motor structure and function, nonverbal intelligence, and age-appropriate expressive and receptive language (cf. Gierut, 1999). Most relevant to the selection process was an errored productive phonological system as determined by performance on the GOLDMAN-FRISTOE TEST OF ARTICULATION (Goldman & Fristoe, 1986). Children's mean performance on this test placed them in the 2nd percentile relative to age- and gender-matched peers (range = less than the 1st to the 18th percentile). This asymmetry between children's typical performance on a battery of developmental measures and their lagging development in phonology established the functional (nonorganic) nature of their speech sound delay.

Phonological samples and analyses

Detailed speech samples were obtained from each child at the time of enrolment into the larger research programme. Standard phonological probes were used to elicit children's spontaneous productions of ambient singletons and 2- and 3-element clusters in picture-naming tasks. Probes consisted of mono- and multisyllabic monomorphs to which present progressive or diminutive suffixes were added (probe words are listed in Gierut, Elbert & Dinnsen, 1987, 477 and Gierut, 1998, 499). Target sounds were elicited in multiple exemplars and contexts, and there was the potential for production of minimal pairs and morphophonemic alternations as evidence of the phonemic status of sounds. Probe responses were digitally recorded and phonetically transcribed by trained listeners using narrow notation of the IPA. Interjudge reliability of transcriptions was calculated on 25% of the probe data obtained from each child. Mean point-to-point consonant agreement was 94% (range = 83% to 99%). The transcribed probe data were then entered into a computerized archive for computational *post hoc* analyses of the type used in the present study. For each child, approximately 375 tokens were entered into the analyses. Of the approximately 41,250 tokens considered, only 80 of the total number of productions (0·19%) were variable in segmental composition due to, for example, morphophonemic alternations; hence, children's outputs were quite stable.

Archival data were next examined relative to the claims of each implicational law. The occurrence of clusters relative to affricates, and of liquid clusters relative to a liquid distinction were evaluated separately; however, a common and conjoined set of criteria was used. Criteria were established to parallel those adopted by Lleó & Prinz and Archibald, but with the specific population in mind. Recall that in the prior studies, relational criteria were employed with direct mappings between a speaker's output and intended target sounds. Yet, following recommended procedures for children with phonological delays (Dinnsen, 1984), independent criteria were additionally adopted. Independent analyses take into account a child's output regardless if correct relative to the target phonology. As will be shown, relational analyses alone may be inadequate in capturing lawful patterns of occurrence.

The operational criteria for the cluster–affricate law were as follows. To be credited with an affricate in the inventory, a child had to produce two unique sets of minimal or near minimal pairs involving affricates, following Gierut, Simmerman & Neumann (1994; this also achieves the criterion of phonetic status as outlined by Stoel-Gammon, 1985). Minimal pairs could be target-appropriate relative to English (e.g. 'chip' [tʃɪp] vs. 'lip' [lɪp]), but they did not have to be (e.g. 'mouse' [maʊts] vs. 'mouth' [maʊθ]). The context of occurrence was not constrained given Lleó & Prinz's finding that affricates emerge in onset before coda position. Voicing of affricates was also free to vary such that voiced and/or voiceless affricates were counted equivalently. From an independent perspective, these data demonstrated that a child used affricates phonetically and phonemically. In addition, a child had to produce an affricate where a target English affricate was called for on the phonological probes with at least a 20% correspondence. For example, if 10 probe items sampled affricates, then a child was minimally required to produce an affricate in at least two of these items. Again, affricates did not need to be accurate relative to target English. From a relational perspective, this showed that a child used affricates with some consistency in contexts necessitated by the target language. If the independent use of affricates in minimal pairs and the relational mapping of affricates to target words both obtained, then a child was credited with having affricates in the sound system. If only one criterion was satisfied, or if neither was fulfilled, then a child was said to have no affricates. These criteria thus established for each child whether the unmarked property of affricates was present in the phonological system.

Turning to the marked property of clusters, a comparable conjunction of criteria was applied to the data. Clusters were operationally defined as consisting of two skeletal slots following Lleó & Prinz, and consistent with their analyses, consonant+glide sequences were included but fricative+obstruent stop sequences were not.[1] As with affricates, a child had to produce clusters (albeit correct or incorrect) in two unique outputs in word-initial position, following Stoel-Gammon (1985). This established that complex onsets consisting of consecutive segments were used, in contrast to other simpler onsets consisting of single segments. There also had to be a relational correspondence between a child's cluster productions and probe items

[1] The status of fricative+nasal stop sequences as true clusters has been debated in the literature (Barton *et al.*, 1980; Selkirk, 1982; Barlow, 2001). In this study, 4 of 110 children (3·6% of the study population) used fricative+nasal stop clusters to the exclusion of other cluster types. This notwithstanding, at the suggestion of one reviewer, fricative+nasal stop clusters were excluded from our analyses for the most conservative interpretation of the data. These four sound systems were thus classified as unmarked in composition, yet still in conformity with the proposed implicational laws.

consisting of target clusters; but in this case, the mapping was to occur for a minimum of 80% of the relevant items (Archibald, 1998, 209, personal communication). That is, a child was required to produce clusters on 80% of the probe items that sampled target clusters. Importantly, the relational criterion for clusters was set more stringently than as above for affricates so as to prevent Type I errors, whereby a child would be credited with marked phonological properties when, in fact, these had not yet been internalized in the grammar. The relevance is that a more stringent criterion constrains the number of false counterexamples (or violations) to the markedness relationship between clusters and affricates, thereby providing a conservative interpretation of the data. Thus, to be credited with clusters in the sound system, a child had to produce onset clusters twice and with an 80% mapping to target clusters. Notice that an 80% mapping necessarily guarantees a two time occurrence of clusters, but not the reverse; therefore if only one, or neither of the criteria was demonstrated, then a child was said to have no clusters in the phonological system.

Following the application of these operational definitions, each child was assigned to 1 of the 4 logically possible cells shown in Table 1. Then, the total number of children in each cell was tallied in evaluation of the lawfulness of clusters relative to affricates.

The entire process was repeated in evaluation of clusters relative to liquids, with two noted changes in the procedures. The reason for these changes stems from the specific formulation of this implicational law; namely, the occurrence of a consonant+liquid cluster implies a liquid distinction, but not *vice versa*. Given this, in order to be credited with a liquid contrast, a child had to fulfill the independent (minimal pair) and relational (20% mapping) criteria for EACH of the liquids /l/ and /r/. As such, a child might have evidenced 0, 1, or 2 liquids in the sound system. Moreover, if both liquids occurred, they had to be present in the same context so as to prevent any complementary (i.e. noncontrastive) distributions. To be credited with a cluster, a child had to again achieve the independent and relational criteria, but specific to consonant+liquid clusters. These could be either or both consonant+l or consonant+r sequences. In accord with these modifications, the data were again organized into the four logically possible cells and tallied across children to test the lawfulness of clusters relative to liquids.

RESULTS AND DISCUSSION

The results of applying two independent implicational laws to the sound systems of 110 children with phonological delays are presented from quantitative and qualitative perspectives. From a quantitative view, we document the number of children who exhibit permissible inventory types in accordance with each of the proposed laws. This is extended by considering the intersection of the two laws across children's sound systems. The

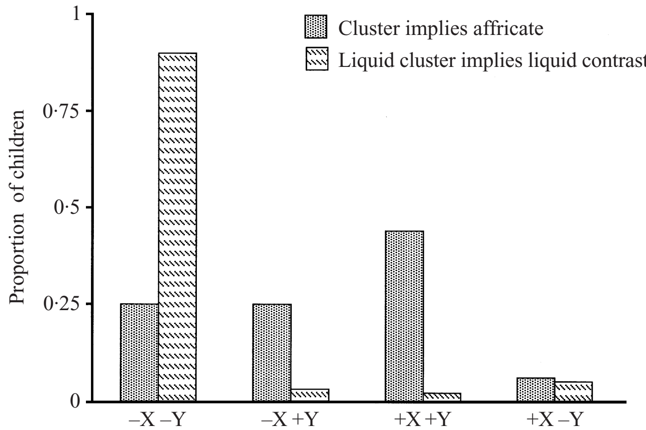

Fig. 2. Inventory composition relative to each implicational law.

qualitative view supplements this by examining the phonological outputs of children who appear to violate the laws as potential counterexamples. The results are then collectively discussed relative to deterministic models of phonological acquisition for insight to a developmental course of cluster acquisition.

Lawfulness of inventories

Figure 2 displays the proportion of children who presented with each of the four logically possible types of inventories that derive from Lleó & Prinz's hypothesis that clusters imply affricates, but not *vice versa*. Of 110 children who participated, 103 presented with a sound system that was fully in accord with this markedness relationship, thereby comprising 94% of the study population. Of the 103 affirmative cases, 28 children evidenced no clusters and no affricates in the repertoire. Another 27 children evidenced unmarked affricates, but not the marked category of clusters. The majority, consisting of 48 children, maintained both marked and unmarked properties evidencing clusters and affricates alike. The average ages of children in these subgroups were 4;1, 4;4, and 4;9, respectively.

For completeness, seven children used clusters to the exclusion of affricates. This pattern should not have lawfully occurred because the marked property (clusters) occurred without also the unmarked property (affricates). These cases constituted the apparent counterexamples that we will consider in the subsequent discussion. It is worth noting that children who violated the cluster–affricate relationship were of the same age (4;1) as the youngest children who produced no affricates and no clusters.

For the most part then, Lleó & Prinz's proposal was supported by the data from children with phonological delays. Markedness appeared to reflect the developmental sequence of emergence of affricates relative to clusters. Although the data were cross-sectional in nature, average ages of the children increased as their sound systems progressed from having no affricates, to affricates, to affricates and clusters. This is consistent with Lleó & Prinz's longitudinal descriptions of the acquisition of cluster in typical development and broadly serves to replicate their results.

Turning to Archibald's hypothesis, a comparable set of findings obtained, also shown in Figure 2. The sound systems of 105 of the 110 children were wholly consistent with the premise that consonant + liquid clusters imply a liquid distinction, but not *vice versa*. This accounted for 95% of the population studied. Of the confirming cases, 100 children evidenced no liquid clusters and no liquid contrast. There were three children who maintained the 2-way liquid contrast, but did not also use liquid clusters. Only two children were found to produce both marked liquid clusters and the unmarked liquid contrast. Mean ages of children in these subgroups were 4;5, 5;5, and 6;2, respectively.

To round out the logical possibilities, five children produced liquid clusters without the necessary liquid contrast, serving as potential counterexamples to the law. Their mean age (4;4) was comparable to the youngest children who presented with no liquid clusters and no liquid contrast, paralleling the cluster–affricate counterexamples.

It is of note that an overwhelmingly large number of children fell into the category of no liquid clusters and no liquid contrast. Within this category, however, it was possible to subdivide children who excluded liquids entirely from those others who had one liquid, but not yet the required 2-way liquid contrast. This further delineation showed that 70 children produced no liquids, but 30 produced at least one liquid. Average ages were 4;3 and 4;9, respectively. Children who produced one liquid were most likely to use /l/ rather than /r/ by a ratio of 3:2 (i.e. 18 with /l/, 12 with /r/). These data lend a finer-grained characterization of the emergence of the liquid contrast than might have been discerned from Archibald's more general proposal.

Thus, the hypothesized relationship between liquid clusters and a liquid contrast was largely confirmed by our data with one addition. Ages of children with phonological delays traced a progression from 0 to 1 to 2 liquids, followed by liquid clusters. This observation from first (albeit delayed) language acquisition offers a tentative hypothesis for second language acquisition about the expected course of development of a liquid distinction by adult learners.

Together, the quantitative results largely supported the lawful and developmental association between clusters and affricates, and clusters and liquids as documented for children with phonological delays. Although the two laws made independent predictions, there were similarities in the way in which children's inventories patterned. This notwithstanding, there was a striking asymmetry in the data that is captured in Figure 2. Specifically, the cluster–affricate and cluster–liquid results were in an inverse relationship. That is, the majority of children had both marked and unmarked properties of the cluster–affricate law (i.e. +X +Y); whereas, it was just the reverse for the cluster–liquid law, where the majority had neither marked nor unmarked properties (i.e. −X −Y). Because these differential patterns came from one and the same population of children, they may be indicative of a potential precedence between the laws; namely, the cluster–affricate relationship may have been implemented prior to the cluster–liquid relationship. If true, then these seemingly independent laws may, in fact, be related. This hypothesis can be tested by integrating the implicational laws across children's systems.

Typological precedence

The intersection of laws was established by crossing the classification of each child's inventory as 1 of the 4 logically possible types along the cluster–affricate dimension with the corresponding classification along the cluster–liquid dimension. For example, if a child presented with no clusters but affricates, and this very same child presented with no liquid clusters and no liquids, then the intersection of these would be −X +Y with −X −Y, following from Table 1. Figure 3 plots the intersecting data for the lawful (confirmatory) cases cited above; apparent counterexamples were set aside for later qualitative inspection.

A first point of mention is that two intersecting cells were phonologically impossible. These are noted by asterisks in Figure 3. Each of these required the absence of any type of cluster along the cluster–affricate dimension, but the presence of liquid clusters along the cluster–liquid dimension. Obviously, it is not possible to claim that clusters are generally absent, but specifically present in a sound system; consequently, these were not considered.

Two other intersections also did not obtain, as shown by open histograms in Figure 3. These gaps were associated with children who would have been classified as having a liquid contrast, but no consonant+liquid clusters (i.e. −X +Y) along the cluster–liquid dimension. One omission was the occurrence of a liquid contrast in the absence of affricates in the system. A second was the occurrence of a liquid contrast in the absence of some other kind of cluster. No children evidenced these types of sound systems, suggesting that affricates and nonliquid clusters may have been needed for the emergence of a liquid distinction. This observation is bolstered by two remaining intersections that did obtain in the data.

Figure 3 shows that children who did not have a liquid contrast or liquid clusters (i.e. −X −Y on the cluster–liquid dimension) were variable in their corresponding classification on the cluster–affricate dimension; this is depicted by shaded histograms. Although some children did not produce either affricates or liquids, 66 of 99 children had affricates in place. For the majority

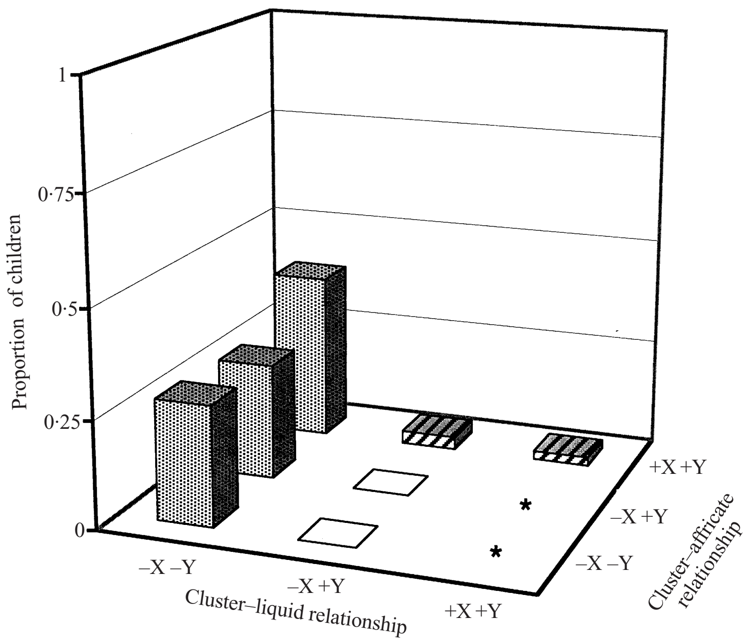

Fig. 3. Cross-classification of inventory composition by implicational law for 99 confirmatory cases.

then, affricates preceded a liquid contrast. The same was true with respect to nonliquid clusters: 39 of 99 children produced some type of cluster. Despite the noted variability, affricates and nonliquid clusters occurred in the systems of these children prior to a liquid contrast and liquid clusters.

Related support comes from those other children who did have a liquid contrast, either with or without also liquid clusters. The relevant data are depicted by hatched histograms in Figure 3. All children with a liquid contrast produced affricates. Moreover, all children with liquid clusters produced other nonliquid clusters. Again, the data suggest that affricates precede a liquid distinction, but importantly, so do other types of clusters.

The intersection of these data indicates that the cluster–affricate law was indeed implemented prior to the cluster–liquid law for children of this study. This replicates previous research which has reported that affricates precede liquids in phonetic and phonemic acquisition (Dinnsen, 1992; Gierut *et al.*, 1994). However, the real significance of this finding lies in the linking of two implicational laws originally thought to be independent. From the integrated data, it is possible to formulate a potential developmental sequence; namely, the occurrence of liquid clusters implies a liquid distinction, which in turn implies nonliquid clusters, which likewise implies affricates. Theoretically, this has implications for deterministic models of phonological acquisition as they bear specifically on clusters.

A deterministic account

Deterministic models of phonological acquisition have been long advanced in account of various properties of children's sound systems including, for example, distinctive features (Rice & Avery, 1995), phonetic classes of place, voice or manner (Leonard, Newhoff & Mesalam, 1980), syllable shape (Levelt, Schiller & Levelt, 1999/2000), and stress (Gerken, 1996). Following Jakobson (1968), the assumption is that properties of human language are predetermined, predictable, and derived from implicational laws. As such, they must be extracted by a child from the input of the surrounding speech community. A child presumably asks and answers a fixed and ordered set of questions about the native language, in much the same format as a conventional decision tree. For each question, a definitive answer must be arrived at before a child may advance. Answers are determined from positive evidence that a child receives from the input in support of the occurrence of certain phonological properties in the language (Goad, 1998). Some have maintained that negative evidence is also pertinent in demonstrating systematic gaps in a phonological system (Fikkert, 1995). While the role of negative evidence remains an issue of debate, there is recent support for its relevance in both first and second language acquisition (Hayes, in press; Swanson, 2002). Through this deterministic process, a child apparently comes to discover the unique grammar of the native language. Representative illustrations of deterministic accounts of phonological acquisition may be found in Dinnsen (1992), Ingram (1992), and Rice & Avery (1995).

As applied herein, our integration of two implicational laws may be revealing of the order in which children evaluate properties of their native language. Specifically, a child would first need to decide whether the language permits affricates as branching segments. Once a definitive 'yes' or 'no' answer is arrived at from the input, the child would next ask whether the language allows sequences of consonants in onset position. A definitive answer to this would prompt the next questions regarding a contrast between /l/ and /r/, and then, the occurrence of consonant+liquid clusters. By this account, the acquisition process would provide for an orderly elaboration of onsets in terms of featural and segmental composition, branching structure, and sonority relationships, consistent with the explanations offered by Lleó & Prinz and Archibald.

Within a deterministic account, there would be room for child- and language-specific variation. Child-specific differences may be captured by the rate at which children evaluate the input and arrive at solutions in the decision tree. Language-specific differences may captured in a child's actual answers to the questions. Some children will answer 'yes,' the native language has a certain property (e.g. affricates), whereas others will answer 'no,' given differences in the input. It is thereby possible for a language to lack predicted precursors to onset clusters; nonetheless, a child would still have been required to evaluate the input for their occurrence in the expected developmental sequence (Dinnsen, 1992; Rice & Avery, 1995).

A deterministic account of cluster acquisition may also be revealing of a cyclic mechanism of change. The construct of cyclicity has been cited within other domains of language and acquisition (Kiparsky, 1982; Gierut, 1996, 1998 and references therein). Previously, cyclicity in acquisition has been observed at levels of the distinctive feature and the word; the present findings may now extend this to intermediate structures. Specifically, we observed that children expanded their repertoire of onsets in a phased relationship between (affricate) singletons, (nonliquid) clusters, (liquid) singletons, (liquid) clusters. This may be defined as cyclic elaboration of segmental, then prosodic structure. There is independent support for the possible cycle at the segmental level. The fact that affricates occurred prior to a liquid distinction follows from implicational laws of phonetic and phonemic complexity, whereby liquid distinctions have been shown to be marked relative to affricates (Dinnsen, 1992; Gierut *et al.*, 1994). Similarly, at the prosodic level, that nonliquid clusters occurred prior to liquid clusters follows from the sonority hierarchy and sonority difference (Clements, 1990). The smaller the sonority difference between consecutive segments in onset position, the more marked the cluster, with liquid clusters having a smaller sonority difference than nonliquid clusters.

In future research, a model of cyclic dependency among implicational laws will warrant further validation. As a first step, it will be necessary to document segmental–prosodic cyclicity in cross-sectional, longitudinal, and cross-linguistic studies of typical phonological development. If cyclicity is generally borne out, then it should be possible to apply it specifically to the design of clinical treatment for children with phonological delays. Treatment may focus differentially on marked versus unmarked properties of the integrated law, as well as segmental versus prosodic phases of the cycle (cf. Gierut, 1996). Predictably, treatment manipulations of consonant+liquid clusters will result in the greatest expansion of children's sound systems. Despite these new suggestions for continued research, not all children of this study conformed to the predicted developmental patterns. These children warrant attention because they too may serve to motivate future studies.

Other alternatives

In all, there were 12 seeming violations of the proposed implicational laws, with seven of these in reference to the cluster–affricate relationship and five others to the cluster–liquid relationship. One child appeared to violate both laws, using marked clusters without the unmarked precursors (however, see O'Connor, 1999). By a deterministic account, these cases should not have been observed because all children were presumably extracting lawful phonological relationships from their shared input of English. An important question is whether these seeming violations were 'true' or due to other sources. Qualitative inspection of the data revealed three possible reasons for the noted exceptions.

A first reason is methodological. Recall that a child had to meet a conjunction of independent and relational criteria to be credited with affricates (or liquids) in the system. The independent criterion necessitated two unique sets of minimal pairs, and the relational criterion set a minimum percentage correspondence between a child's output and the intended adult target. For 6 of the 12 potential counterexamples, one but not both of these conditions obtained; namely, children fulfilled the independent but not also the relational standard. Illustrative data are shown in Table 2. For example, Child 19 used /tʃ/ in minimal pairs, but not for intended target affricates. Child 104, on the other hand, maintained a contrast between /l/ and /r/ for target liquids, but there was only a relational correspondence for 5 of 34 items, falling short of the required mapping. These observations suggest that the independent criterion alone may have been sufficient in discerning lawful (and confirmatory) relationships among sounds. The research implication is that it may be more appropriate to view children's sound systems as independent grammars, rather than in reference to the adult (Leonard *et al.*, 1980; Dinnsen, 1984). In future studies, methodologies that rely on relational comparisons may be deemed too stringent in establishing systematicities of children's sound systems.

A second reason for the presumed violations is phonological in nature. In 5 of the remaining 12 cases, children produced target clusters and affricates in exactly the same way, with no differentiation in their surface phonetic outputs. Table 2 shows representative data from Child 43 who produced ambient clusters and affricates as [fw], and Child 106 who produced these as obstruent stop+l sequences. In both cases, the distinction between clusters and affricates was merged. One possibility is that putative clusters were not really clusters at all, but instead functioned as affricates in these sound systems. That clusters may behave phonologically like affricates is not a new hypothesis (Menyuk, 1972; Barton *et al.*, 1980); but here, the neutralization of clusters and affricates can be traced to their structural similarity (cf. Lleó & Prinz, 1997). Clusters and affricates both involve branching structure at the level of the onset and segment, respectively (Figure 1). Children may have recognized and overgeneralized the common characteristic of branching by merging two phonological categories into one output. For future research, it will be necessary to not only consider the occurrence of sounds, but also their function in a child's grammar. This again underscores the potential

TABLE 2. *Sources of apparent violations of markedness*

I. Methodological					
Child 19 (3;8)					
Affricates are contrastive		But lack minimum target correspondence			
[ɑɪtʃ] – [ɑɪb]	'ice' – 'knife'	[ʃu]	'cheese'		
[maʊtʃ] – [maʊp]	'mouse' – 'mouth'	[xɔk]	'chalk'		
		[kɪkɛn]	'kitchen'		
		[wɔki]	'watch-i'		
		[piʔ]	'peach'		
		[wɔk]	'watch'		
Child 104 (3;10)					
Liquids are contrastive		But lack minimum target correspondence			
[laɪʔ] – [aɪʔ]	'light' – 'ice'	[wɛk]	'leg'	[waɪʔ]	'ride'
[liʔi] – [tiʔi]	'leafy' – 'teeth-i'	[weɪʔi]	'lady'	[wʌm]	'run'
[riʔi] – [tiʔi]	'wreath-i' – 'teeth-i'	[tʌwʊ]	'color'	[kɛwɪt]	'carrot'
[drɛʔi] – [bɛʔi]	'dressy' – 'bed-i'	[jɛwoʊ]	'yellow'	[dɔʔi]	'starry'
		[neɪoʊ]	'nail'	[dijʊ]	'deer'
		[hɪw]	'hill'	[doʊ]	'door'
II. Phonological					
Child 43 (3;11)					
Clusters as [fw]		Affricates as [fw]			
[fwɛʔ]	'dress'	[fwɔk]	'chalk'		
[fwoʊ]	'throw'	[fwɪkɛn]	'chicken'		
[fwɔɪ]	'drive'	[fwɪp]	'chip'		
[fwɪm]	'swim'	[fwʌmp]	'jump'		
[fwihaʊ]	'treehouse'	[fwɛwi]	'jelly'		
[fwaʊwə]	'flower'	[fwiːp]	'jeep'		

Child 106 (4;3)							
Clusters as obstruent stop+l		Affricates as obstruent stop+l					
[blum]	'broom'	[tlɔt]	'chalk'				
[tli]	'tree'	[tlɪp]	'chip'				
[klaɪ]	'cry'	[tlɛʊ]	'chair'				
[dlɛd]	'thread'	[dlʌmp]	'jump'				
[pleɪt]	'plate'	[dlɛwi]	'jelly'				
[glu]	'glue'	[dlɛʊ]	'jail'				
[tlɪt]	'twist'						
[klæt]	'quack'						
III. Typological							
Child 31 (4;4)							
Affricates are contrastive		/l/ is contrastive		Consonant+l clusters		Target /r/ as [w]	
[tʃɪp] – [wɪb]	'chip' – 'web'	[liθ] – [tiθ]	'leaf' – 'teeth'	[slaʊwʊ]	'flower'	[wæbɪʔ]	'rabbit'
[wɔtʃi] – [wɔki]	'watch-i' – 'rocky'	[laɪt] – [baɪt]	'light' – 'bite'	[glʌbz]	'glove'	[wʌn]	'run'
[bædʒi] – [bæθi]	'badge-i' – 'bath-i'			[bloʊwɪn]	'blowing'	[tɛwɛʔ]	'carrot'
[teɪdʒi] – [tɛɪli]	'cage-i' – 'tail-i'			[bluhaʊθ]	'bluehouse'	[dɪwi]	'deer-i'
						[tʃɛʊ]	'chair'
						[dɔː]	'door'

importance of an independent evaluation of a child's outputs for a cohesive description of the sound system.

A third source of the apparent counterexamples is both methodological and typological and pertains to the one remaining violation. The relevant data in Table 2 are from Child 31, aged 4;4. This boy produced affricates target-appropriately as /tʃ dʒ/. He also produced /l/ and consonant+l clusters. However, target /r/ surfaced as [w] across contexts, with only one phonetic occurrence in the entire sample (i.e. 'crashing' [træʃɪŋ]). Child 31 therefore did not maintain the necessary phonemic contrast between /l/ and /r/ for production of liquid clusters. While it is possible that the liquid distinction was maintained, it could not be detected from available articulatory phonetic data. Supplementary acoustic analyses may have shown that production of [w]'s corresponding to target /r/ were unique from other [w]'s corresponding to target /w/. The speech samples of this study were limited in this regard because multiple repetitions of a given set of words were not elicited, but in future research, these may be relevant for acoustic comparisons.

This notwithstanding, Child 31 remains an interesting case. On the one hand, he seemed to violate one particular implicational law; but on the other hand, his production pattern was wholly consistent with another complementary law. Specifically, the RESOLVABILITY PRINCIPLE (Greenberg, 1978) states that a language with a consonantal sequence of length *m* will also have a subsequence of length *m-1*. As applied herein, the Resolvability Principle predicts that the occurrence of consonant+liquid clusters implies also the occurrence of at least one liquid (for other applications in acquisition, see Eckman, 1991; Gierut & Champion, 2001). This explicitly fits the description of Child 31's system where liquid /l/ was in a subset relationship with consonant+l clusters. Notice that the Resolvability Principle differs from Archibald's original proposal in that there is no requirement of a liquid contrast. Because of its less restrictive formulation, the Resolvability Principle may, in fact, supersede Archibald's law. Consider that if a sound system complies with the cluster–liquid law, it will also comply with the Resolvability Principle but not *vice versa*. One research implication is that the Resolvability Principle alone may accurately capture the full range of patterns in children's acquisition of clusters relative to liquids. Future studies will need to determine if there are empirical or developmental differences between these typological descriptions. In all, these 12 apparent violations highlight methodological, phonological, and theoretical alternatives that will likely need to be incorporated in continued work adopting a lawfulness approach to phonological acquisition.

In conclusion, an appeal to implicational laws as a research orientation has yielded new insights into cluster acquisition. At the very least, this archival study has replicated two implicational laws in a unique population of children with phonological delays. This convergence of evidence helps to better establish the strength and validity of proposed lawful relationships involving clusters. In the process, however, the two independent laws were found to be related such that one implicational relationship was put in place before the other. A set of precursors to cluster acquisition was thereby identified and shown to be recursive. Notably, this was revealing of a potential deterministic course in children's acquisition of onset clusters.

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