

Phonological Complexity and Language Learnability

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Purpose: To extend formal models of language learnability to applications in clinical treatment of children with functional phonological delays.

Method: The focus of the narrative review is on phonological complexity. This follows from learnability theory, whereby complexity in the linguistic input to children has been shown to trigger language learning. Drawing from the literature, phonological complexity is defined from epistemic, ontological, and functional perspectives, with specific emphasis on the application of

language universals in the selection of target sounds for treatment.

Results: The cascading effects of phonological complexity on children's generalization learning are illustrated, and frequently asked questions about complexity in treatment are addressed.

Conclusion: The role of complexity in cognitive development is introduced to demonstrate the apparent robustness of effects.

Key Words: linguistic complexity, phonological acquisition, treatment efficacy

Children's acquisition of language occurs rapidly, with relatively few errors and seemingly without effort. In a matter of just about 36 months, a child typically produces novel sentences that involve complicated constructions, words that reference abstract ideas or absent entities, and sound sequences that mark the distinctive contrasts of the native language. In order to achieve this, a child must attend to the available input of the surrounding speech community (Morgan & Demuth, 1996). Linguistic input is thus the primary evidence for language learning, whether one views language as innately guided (Chomsky, 1999) or computationally derived (Bates & MacWhinney, 1987).

Despite its importance, the linguistic input that a child receives is often variable, degraded, or even lacking in cues that would help to uncover the structure and organization of the language being learned (Gleitman & Newport, 2000). How then does a child use less-than-perfect input to guide language learning in extracting salient islands of information that are, in turn, revealing of linguistic structure? And importantly, for children with language delays, how can the input best be structured and presented in clinical treatment so as to facilitate the language learning process? These questions form the basis of *learnability theory* and its explicit focus on complexity as the trigger of language learning. In this article, complexity is examined within this broader theoretical context to best illustrate its clinical utility. This complements and extends prior discussions of the developmental and clinical factors that are associated with complexity (Gierut, 2001; Gierut, Morrisette, Hughes, & Rowland, 1996). The emphasis herein is on the

phonological properties of language and their acquisition by children with functional phonological delays. Three questions are addressed: (a) What is "complexity"? (b) How does complexity trigger language learning? and (c) What aspects of linguistic complexity enhance phonological generalization in the clinical setting? It will be shown that parallel instances of complexity are also exemplified in other facets of child development.

Operational Definition of Complexity

Complexity has been the focus of study in a broad range of disciplines, including but not limited to linguistics (Dahl, 2004; Mohanan, 1992), cognitive and developmental psychology (Casti, 1994; Thelen & Smith, 1994), education (Gagné, 1977), philosophy (Peirce, 1935), evolutionary biology (Holland, 1995), and computer science (Simon, 1981). Yet, it is striking that few have offered a comprehensive operational definition of complexity. In this regard, Rescher (1998) makes an important contribution by defining three "modes" or ways of conceptualizing complexity. These include complexity from *epistemic*, *ontological*, and *functional* perspectives.

Complexity from an epistemic perspective refers only to the description of a system, and therefore is most elementary. From this vantage, complexity is reflected in the number of descriptor terms that are needed to define a system. Complexity is also reflected in the level of detail associated with solving a problem, or in the energy, time, or money expended to solve that problem. As applied to the clinical domain, complexity

at an epistemic level begins with the assessment process in the initial description of a child's errored sound system. For example, to adequately characterize a given child's pattern of errors, it may be necessary to appeal to multiple and varied phonological processes, and these may further interact (e.g., Dean, Howell, Waters, & Reid, 1995; Dinnsen & O'Connor, 2001; Greenlee, 1974; Tyler, Edwards, & Saxman, 1987). This phonological description, in turn, may warrant an increased number of treatment goals to bring the child's sound system into conformity with the target language. Likewise, to meet these goals, the duration and/or frequency of the treatment sessions may need to be increased. Thus, complexity from an epistemic perspective bears on phonological descriptions and the general outline of treatment, and is of further concern to health care providers given the costs associated with the administration and duration of treatment.

Complexity from an ontological perspective refers to the constituent elements of a system and their hierarchical organization. This mode of complexity is especially pertinent to language because every module of grammar (syntax, semantics, phonology) is composed of constituent elements that dominate other subconstituent structures. For the sound system in particular, the hierarchical constituents of word-level phonology include featural, segmental, syllabic, and prosodic structures, each of which consists of its own additional internal units (Kenstowicz, 1994). For example, the syllable is organized into the onset, nucleus (vowel), and coda as its constituents. The onset has its own subconstituents that are hierarchically arranged (e.g., timing slots, branching, sonority; Clements & Hume, 1995); the same is true for the nucleus and coda. As applied clinically, complexity from an ontological vantage holds significance for phonological learning and generalization from treatment. As Rescher (1998) explains, it is "easier to get a cognitive grip on a hierarchical system because mastery of the controlling element will in large measure provide the key to unlocking the whole" (p. 12). That is, by exposing a child to higher order phonological constituents in treatment, other related secondary structures will fall into place accordingly (Gierut, 2001; Gierut et al., 1996, and references therein). The end result is a cascading effect on generalization learning. Thus, complexity at an ontological level bears on clinical treatment in the selection of (higher order) target sounds.

Complexity from a functional perspective refers to the principles that govern a system and the corresponding degrees of freedom that are allowed in that system. This type of complexity is also realized in language. With regard to phonology, languages of the world use, for example, different inventories of sounds, phonological rules, and bases for assigning stress (see Kenstowicz, 1994, for examples). This variation (i.e., degrees of freedom) is not without limits, however, because well-defined lawful relationships among sounds constrain the range of possible phonological systems (Greenberg, 1978; Ladefoged & Maddieson, 1996; Lindblom & Maddieson, 1988; Maddieson, 1984). The same is true in the clinical setting for children with functional phonological delays. Children exhibit different types of error patterns, which may come about for very different reasons (e.g., Dinnsen & Chin, 1993; Leonard, Newhoff, & Mesalam, 1980; Stoel-Gammon & Cooper, 1984; Weismer, Dinnsen, & Elbert,

1981). In fact, it is rare to find two children who exhibit exactly the same errors attributable to a single source (e.g., compare children who use ingressive fricatives as reported by Bedore, Leonard, & Gandour, 1994; Gierut & Champion, 2000; Ingram & Terselic, 1983). Despite individual differences, there are striking commonalities across children with phonological delays in their acquisition and errors of sound production (Hodson & Paden, 1981; Shriberg & Kwiatkowski, 1994; Shriberg, Kwiatkowski, Best, Hengst, & Terselic-Weber, 1986; Smit, 1993a, 1993b). These resemblances extend further in mirroring the production patterns of younger children in typical development and adults with fully developed sound systems (Dinnsen, 1992; Dinnsen & Barlow, 1998; Ingram, 1989; Leonard, 1992; Locke, 1983). Thus, the basic structure of sound systems—albeit delayed, typical, or fully developed—appears to be governed by lawful principles that permit variability but maintain systematicity. Given this, the clinical application of complexity from a functional mode comes in the selection of target sounds for treatment that are based on these lawful principles. That is, the laws that unify phonological systems generally may be used as input in treatment so as to expose a child to the governing properties of language. This thereby complements ontological complexity in targeting higher order categories to induce cascading effects on generalization learning. The application of phonological complexity from a functional vantage is elaborated in subsequent sections.

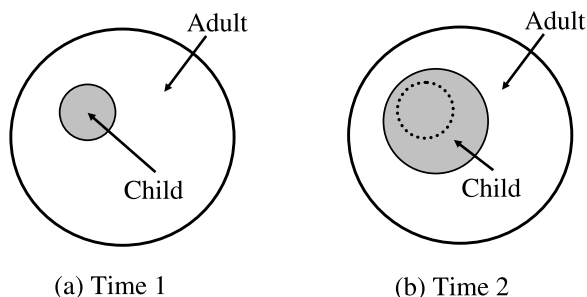
Notably, the three kinds of complexity are distinct and independent. Complexity at one level does not necessarily imply complexity at other levels. To illustrate, a clinician may invoke complexity from an ontological perspective by selecting a higher order phonological constituent for treatment; but because of the generalization gains that are expected, the number of treatment goals, duration, and/or cost of treatment may be significantly reduced from an epistemic perspective. As another illustration, from an ontological vantage, syllable onsets can be complex in their subconstituent structure; but from a functional perspective, the law that governs the assembly of syllable onsets (i.e., Sonority Sequencing Principle; Clements, 1990) is simple in its formulation and transparent in its application. Thus, whereas different types of complexity are complementary, there is no necessary one-to-one correspondence between them.

Complexity and Learnability Theory

Having defined complexity, let us now consider the second question of how complexity triggers language learning within the framework of learnability theory. Learnability theory aims to logically and mathematically formulate the possible ways that language can be learned from the input of the surrounding speech community, with its primary source of data being typical language development (e.g., Matthews & Demopoulos, 1989; Pinker, 1984; Tesar & Smolensky, 1998; Wexler, 1982; Wexler & Culicover, 1980). Most agree that a child's early grammar is in a subset relationship with the adult target grammar. This is illustrated in Figure 1 for two points in time (Pinker, 1995, provides an elegant description of learnability theory and the full set of logically possible relationships between child and adult grammars, some of which are directly

FIG1

FIGURE 1. Schematic of the set–subset relationship between adult and child grammars at two points in time. The scope of the adult grammar is shown as an open circle and the child’s subset grammar, as a shaded circle. As language acquisition proceeds over time from Points 1 to 2 (a to b, respectively), the scope of the child’s subset grammar expands (from shaded to dashed shaded) to better match that of the adult, and this is exemplified by the child’s knowledge and use of increasingly more complex linguistic categories that are available in the (adult) input.



pertinent to children with functional phonological delays). By this depiction, a child uses some of the constructions, structures, or categories of the target language (characterized by the shaded areas in Figure 1), and these are perfectly consistent with those of the adult grammar. Nevertheless, there are other more complicated structures (characterized by the open areas) that the child must acquire before the target language can be considered “mastered.” This takes place gradually over time, as depicted by an increase in the size of the scope of the child’s subset grammar from Figure 1a to 1b.

It should be noted that set–subset relationships are defined in terms of general linguistic categories and operations. For example, if a child demonstrates use of well-formed sentences, the subset grammar must be composed of the relevant linguistic categories and lawful principles that are needed to construct those sentences. It does not imply further that the child is able to, or will, generate all of the infinitely possible sentences of the language. An example from phonology that exemplifies a subset relationship is the observed gaps in phonetic inventories, whereby a child uses some target stops and fricatives but not others, and further, affricates and liquids are never produced or used (Dinnsen, 1992; Tyler & Figurski, 1994). The categories of stops and fricatives then are part of the child’s subset grammar, whereas affricates and liquids are not.

Given the subset grammar, how does a child go about learning the remaining outlying structures of the target language over time? Following from the learnability literature, the child must be provided with crucial input about these more complex components (Pinker, 1995; Wexler, 1982). This is termed *positive evidence*; namely, it is input that illustrates for the child the full range of advanced constructions, categories, and structures that are permissible (“legal”) in the language. Positive evidence is also the driving force behind children’s ability to detect and correct their linguistic errors (Marcus, 1993). Importantly, the positive evidence needed to motivate change must come from outside of the child’s subset grammar. For example, to advance the child’s subset grammar in Figure 1a, positive evidence must come from the open areas

of the adult set. Likewise, once the child’s subset system has expanded to that in Figure 1b, additional positive evidence must be culled from the input, with this coming once again from the open areas of the adult set. By this account, to acquire more, a child must be exposed to more. Continuing the subset example from phonology, relevant positive evidence that would advance the grammar might include affricates and liquids because apparently the child is unaware that these phonological categories are contrastive in target English.

Another possible alternative, however, is to limit the positive evidence to simpler structures in keeping with a child’s current level of performance and/or developmental scales. In such cases, the input would be drawn from within the scope of the child’s current subset grammar (i.e., the shaded areas of Figure 1a or 1b). Here, the suggestion is that to learn more about language, a child should be exposed to more of the same or perhaps even less. Returning to the phonology subset example, simpler positive evidence might come from the classes of stops and fricatives, even though the child already recognizes that these categories are functional in target English. Following from the learnability literature, by this alternative, it would be impossible for the child’s linguistic system to ever advance because the full set of grammatical categories, structures, and operations of the adult language would never be revealed (Wexler, 1982, and references therein). The child would not be exposed to precisely those critical, more complex components that lie outside of the existing subset system. Consequently, there would be no evidence in the input to motivate expansion of the subset grammar so as to better approximate, and ultimately match, the adult system. Under this approach, transitions in growth of a subset grammar, as shown in Figure 1, cannot be induced because the positive evidence that is available in the input is wholly consistent with the child’s (already known) subset system. In fact, it has been shown that simpler input actually makes language learning *more difficult* because the child is provided with only partial information about linguistic structure. Wexler (1982, p. 308) explains that “the presentation of ‘simpler’ data will have no beneficial effect ... but *will* have a detrimental effect on the amount of information that is available to the learner, and thus on the learner’s power of inference” about the structure and organization of the target language.

Importantly, the premises of learnability theory and the ease or difficulty of learning have been borne out in typical language development (Roeper & de Villiers, 1992). For example, “motherese” was initially thought to be an inherent design feature that facilitated language learning by systematically simplifying the input to infants (Brown, 1977; Snow & Ferguson, 1977). Contrary to this hypothesis, it has been well documented that the types of sentences, words, and sounds that mothers use with their children are not simple but rather are complex and represent the full scope of the target language (Newport, Gleitman, & Gleitman, 1973, 1977). With respect to phonology, this has been evidenced, in part, through corpora analyses of mothers’ input to children’s early words (e.g., Ratner, 1993; van de Weijer, 1998). Typically, a child is exposed to many consonant-vowel-consonant forms (e.g., *bib*, *big*, *ball*) in the early stages of language learning; yet it is known that consonant-vowel sequences are universally simpler (Selkirk, 1982). The input that influences children’s

common early words also includes seemingly more difficult later acquired sounds (e.g., *shoe*, *bath*) and sound sequences (e.g., *block*, *clap*). Moreover, children start off by perceptually attending to words in the input with many phonetically similar counterparts (e.g., *cap*, *lap*, *cat*, *hat*; Jusczyk, Luce, & Charles-Luce, 1994), only to later shift to a tack that is more facilitating in spoken word recognition (Luce & Pisoni, 1998). Similarly, children find the rhyme of syllables to be most salient in perception and production (Brooks & MacWhinney, 2000; Storkel, 2002; Treiman & Baron, 1981) when, in fact, the onset of syllables is the prominent context for the preservation of phonemic contrasts (Smith, 2002). Thus, in typical development, the linguistic input that is provided to children (and often the early strategies that they use) appears to be complete and complex.

This raises two clinical questions about the kinds of input that will aid the language learning process for children with functional phonological delays. If complex input triggers language learning in typical development, then is the same also true for delayed development? This is relevant because, as clinicians, we often base our intervention strategies on the course and milestones of typical development (Fey, 1986; Hodson & Paden, 1991; Smit, Hand, Freiling, Bernthal, & Bird, 1990; Van Riper, 1963). A second question is whether children with phonological delays are really able to benefit from complex input. It might seem that this information may be too challenging or too excessive, especially in light of their linguistic lags. Even Wexler (1982) acknowledges that it is possible that some children may require simpler linguistic input due to attentional or processing limitations. This question takes on added significance in the clinical domain because it is possible to directly evaluate the empirical effects of different types of input (simple vs. complex) in treatment. If children with phonological delays do indeed evidence gains following treatment of complex linguistic categories, then concerns about the presumed difficulty of learning such structures can be set aside. In the next section, these questions are addressed by examining the impact of linguistic complexity on the sound systems of children with functional phonological delays.

Complexity of the Input in Clinical Treatment

Phonological complexity can take a number of different forms in keeping with epistemic, ontological, and functional perspectives (for review, see Gierut, 1998, 2001; Gierut et al., 1996). The discussion herein concentrates on the functional level of phonological complexity, beginning with an overview of observed lawful relationships among sounds and sequences, their role in language development generally, and their application to phonological treatment specifically.

Phonological Complexity at a Functional Level

There are specific co-occurrence relationships and tendencies among the phonological properties of language, which are termed *implicational laws* (also, *language universals* or *language laws*). Typically, such laws are discovered by examining the inventories of thousands of languages of the world for patterned occurrences of structures that crosscut sound systems generally (Greenberg, 1978; Ladefoged & Maddieson,

1996; Lindblom & Maddieson, 1988; Maddieson, 1984). The aim is to capture commonalities among languages, but to allow each language its own unique structure, consistent with Rescher's (1998) definition of functional complexity. From the perspective of learnability theory, the laws define the full set of languages of the world, the adult grammar represents one subset of these, and the child grammar represents a further subset of that. Language laws thereby limit the range of possible and expected grammars, and it is in this regard that they begin to have developmental and clinical utility. Specifically, implicational laws are formulated in the following way (parenthetical notations are inserted to reflect development): If a (child's) grammar has the phonological property X, then that (child's) grammar will also have the property Y, but not vice versa. Notice that this is a unidirectional relationship: X governs Y, but not the reverse. Because X is the governing variable, it is higher order and consequently more complex, which bears further on Rescher's notion of complexity at an ontological level. Conventionally, X is called the *marked* property and Y the *unmarked*; the co-occurrence relationship between X and Y is termed *markedness*.

With this background in place, how do laws determine possible grammars in development, and how can laws be used in clinical treatment? To illustrate these points, let us consider the established law "Affricates (i.e., X) imply fricatives (i.e., Y), not vice versa." Table 1 shows the logically possible relationships among affricates and fricatives in a child's grammar. Notice that a child may have no affricates and no fricatives in his or her inventory (first row). Neither the marked (complex) nor the unmarked (simple) property is evidenced. Alternatively, a child may use unmarked fricatives, but not marked affricates (second row). Here, the simple property is observed in the absence of the more complex. A third possible grammar is one where a child uses both affricates and fricatives (third row), thereby exhibiting both complex and simple properties consistent with target English. A final grammar is one where a child uses marked affricates, but not unmarked fricatives (fourth row). Under this scenario, the child presumably produces a complex affricate without also a simpler fricative. While this is a logical alternative, it is in direct violation of the implicational law. The reason is that laws are unidirectional, with the complex always implying the simpler. If affricates imply fricatives, and if affricates occur in the child's sound system, then fricatives should surface as well. Implicational laws thus identify the linguistic precursors to more complex phonological properties. In this example, unmarked

TBL1

TABLE 1. Logically possible relationships among marked and unmarked properties of sound systems and their apparent instantiation in grammar.

X implies Y		Grammar
Marked property affricates	Unmarked property fricatives	
–	–	No affricates or fricatives
–	+	Fricatives, no affricates
+	+	Affricates and fricatives
+	–	Impossible

fricatives are prerequisite to marked affricates. The identification of phonological precursors is one way that implicational laws inform our understanding of language development. Another contribution is that laws reflect the types of grammars (i.e., degrees of freedom) that children may exhibit in the course of language development, as outlined in Table 1.

Implicational laws have further applicability in the selection of target sounds for treatment. Continuing the affricate–fricative example, there are two alternative targets that a clinician may choose for treatment, drawing either from the class of affricates or from the class of fricatives. However, depending on which is selected, there are differential predictions about generalization learning that follow directly from the law. Namely, if a child is treated on a more marked affricate, then the law predicts that unmarked fricatives will also be acquired. Because a complex affricate implies a simpler fricative, generalization is expected to encompass both complex and simple properties, comparable to the grammar shown in the third row of Table 1. Alternatively, if treatment centers on an unmarked fricative, then the law predicts that generalization will extend to acquisition of fricatives. As before, this is due to the unidirectionality of implicational laws and is on par with the grammar shown in the second row of Table 1. The law makes no further predictions about other possible generalization gains following treatment of the unmarked, and consequently the explicit plan for generalization is restricted (cf. Elbert, Powell, & Swartzlander, 1991). Thus, consistent with the premises of learnability theory, the greater benefit to a child’s sound system is expected to follow from treatment of more complex phonological properties. Here, complexity is defined functionally as the higher order marked property of an implicational law. Importantly, the predicted patterns of generalization have been well documented in children’s learning.

Phonological Complexity and Learning Patterns

TBL2 Table 2 lists some of the implicational laws that have been examined with respect to phonological acquisition and treatment; these citations are not meant to be exhaustive (see Gierut, 1998, 2001; Gierut et al., 1996, for additional references). Notice that the list spans a full range of hierarchical structures, from phonetic and phonemic inventories to syllables to phonological processes. In this section, two lawful relationships are presented to demonstrate how complexity at a functional level may be used to select the input of treatment so as to induce generalization learning. The patterns of generalization to be reported are representative of the kinds of change that have been observed in evaluations of other implicational laws.

Before turning to the data, it is necessary to say a few words about how implicational laws are typically evaluated in treatment. For the most part, the available studies have utilized single-subject experimental designs in the manipulation of different treatment targets. The aim is to determine the gains that result when a marked versus an unmarked property of an implicational law is chosen as the treatment target. The independent variables are thus complementary sides of the law, such that some children are taught the simpler property and others the more complex. Assignment of the treatment target is random because children who are recruited do not accurately

use or produce the relevant components of the law; namely, they exhibit 0% baseline performance on both unmarked and marked properties prior to treatment. Also, children who participate exhibit functional phonological errors, with no other apparent delays beyond the sound system. The dependent variable that provides the basis for comparison is generalization learning. While generalization has been operationalized in different ways across studies (as illustrated below), the constant and crucial data pertain to both marked and unmarked properties of the law. That is, both simple and complex categories are probed to establish generalization gains, independent of the assigned treatment target. Generalization gains are determined relative to children’s baseline performance to establish the effects of the input on learning. To highlight these relevant comparisons, two related implicational laws that define the occurrence of clusters in sound systems are presented in brief below. The reader is referred to primary sources for additional details about the children’s phonologies, treatment procedures and stimuli, probe administration, and expanded discussion of treatment effects. (Participant numbers correspond to those of the original reports.)

A first law states that clusters imply affricates, but not vice versa (Gierut & O’Connor, 2002; Lleó & Prinz, 1996, 1997). Clusters are therefore marked and complex relative to affricates. On representational grounds, this is due to the branching nature of these sequences (Lleó & Prinz, 1997). Figure 2 plots the generalization learning of two children who received treatment guided by this law (Gierut, 2002, 2003). Child 154 (age = 3;2 [years;months]) was provided the more complex input, being treated on the cluster /tw-/, whereas Child 147 (age = 3;1) was given the simpler input, being treated on the affricate /tS-/. Keep in mind that, prior to treatment, neither child used affricates phonemically, nor were clusters produced. From the posttreatment display, it can be seen that Child 154 evidenced 100% use of the treated cluster in untreated probe words. This child also generalized to a range of other clusters, with these being used in 79% of relevant probe items. Moreover, untreated affricates /tS dZ/ emerged, being used in 62% of relevant probe words. In comparison, Child 147 generalized the treated affricate to 29% of untreated probe words but showed little to no further generalization, either to other affricates (i.e., use of /dZ/) or clusters. As predicted by the law, Child 154 evidenced greater generalization learning when treatment was directed at a marked property, with transfer to both marked and unmarked categories.

A second law that bears on clusters states: “Clusters with a small sonority difference between consecutive segments imply clusters with a greater sonority difference, but not vice versa” (Davis, 1990; Steriade, 1990). *Sonority* is a relative measure that is directly correlated with intensity (i.e., acoustic energy) and inversely correlated with intraoral air pressure (Parker, 2002). Sounds that are highly sonorous are produced with greater intensity and lower intraoral air pressure. Conversely, sounds that are low in sonority are produced with less intensity and greater intraoral air pressure. *Sonority difference* is a comparison of the sonority of segments as determined by simple algebraic formula (Steriade, 1990). (The computation of sonority difference is not crucial to the immediate discussion, but the interested reader is referred to instructions provided in Gierut, 1999, pp. 709–710.) On a continuum, the least

FIG2

TABLE 2. Some implicational laws observed in phonological acquisition and treatment, with examples of complex treatment targets for the associated errors.

Hierarchical properties of sound systems	Observed implicational relationships	Acquisition evidence	Examples of complex treatment targets ^a
Phonetic inventory	A stridency and/or laterality distinction implies the phonetic occurrence of a liquid, which implies a fricative and/or affricate, which implies a voice distinction among cognate stops, which implies a nasal and glide. ^b	Tyler & Figurski, 1994	/s/ in contrast to /T/ /z/ in contrast to /D/ /r/ in contrast to /l/
Phonemic inventory	Consonants imply vowels. Affricates imply fricatives. Fricatives imply stops. Voiced obstruents (i.e., stops, fricatives, affricates) imply voiceless obstruents. Liquids imply nasals. Velars imply coronals.	Robb et al., 1999 Dinnsen et al., 1992 Dinnsen & Elbert, 1984 McReynolds & Jetzke, 1986 Gierut et al., 1994 Stoel-Gammon, 1996	Consonant excluded from the child's phonemic inventory /tS dZ/ /f v T D s z S Z/ /b d g/ /v D z Z/ /dZ/ /l r/ /k g/
Distributional properties	Fricatives in initial position imply fricatives in final position. Stops in final position imply stops in initial position. Word-initial /r/ implies post-vocalic /r/.	Ferguson, 1977 Dinnsen, 1996 Smit, 1993a	Word-initial /f v T D s z S Z/ Word-final /p b t d k g/ Word-initial /r/
Syllable structure	Clusters imply singletons. Clusters imply affricates. Clusters with a small sonority difference imply clusters with a greater difference. Fricative+Liquid clusters imply Stop+Liquid clusters. Liquid onset clusters imply a liquid in coda position.	Gierut & Champion, 2001 Gierut & O'Connor, 2002 Gierut, 1999 Elbert et al., 1984 Baertsch, 2002; Fikkert, 1994	Cluster, with exception of s+obstruent stop sequences ^c Cluster ^c /fl- fr- Tr- Sr-/ /fl- fr- Tr- Sr-/ /pl- pr- bl- br- tr- dr- kl- kr- gl- gr-/ /fl- fr- Tr- Sr-/
Phonological processes	Stopping (e.g., [b] for /v/) implies liquid gliding (e.g., [w] for /r/). ^d Manner assimilation (e.g., [n/n] "won") implies liquid gliding (e.g., [w] for /r/). ^d Spirantization (e.g., [s] for /t/) implies place assimilation (e.g., [gçg] "dog"). ^d Progressive place assimilation (e.g., [bop] "boat") implies regressive place assimilation (e.g., [gçg] "dog"). ^d Velar fronting word-finally implies velar fronting word-initially. ^d The absence of a voice contrast in final position implies the absence of a voice contrast in initial position. ^{d,e} Errors of weak syllable deletion in syllables beginning with an obstruent imply like errors in syllables beginning with a sonorant. ^d	Dinnsen & O'Connor, 2001 Dinnsen & O'Connor, 2001 Dinnsen & O'Connor, 2001 Stoel-Gammon, 1996 Morrisette et al., 2003 Dinnsen et al., 2001 Kehoe & Stoel-Gammon, 1997	/w/ in contrast to /r/ to eliminate liquid gliding /w/ in contrast to /r/ to eliminate liquid gliding /t d/ in contrast to /k g/ to eliminate place assimilation Word-initial /t d/ in contrast to /k g/ to eliminate regressive place assimilation Word-initial /t d/ in contrast to /k g/ to eliminate velar fronting Word-initial voiced obstruent in contrast to voiceless obstruent to eliminate devoicing Multisyllabic words containing unstressed syllables beginning with a sonorant (e.g., "te _l phone," "di _n osaur") to eliminate weak syllable deletion

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^aAny one of the examples in the corresponding cell represents a complex treatment target.

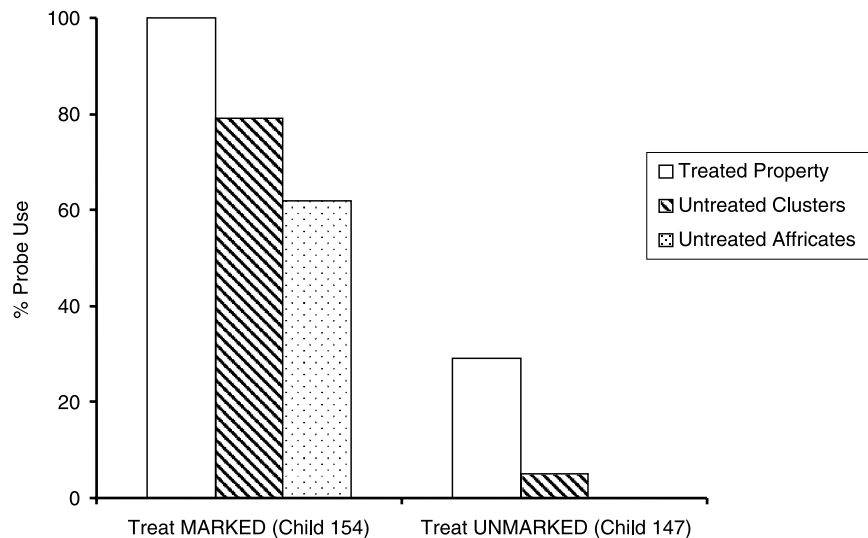
^bThis is a relative markedness relationship that involves a chain of phonetic properties (see Dinnsen, 1992, for details). Phonetic inventories are determined by a two-time occurrence of a sound independent of context and accuracy (Stoel-Gammon, 1985), and distinctions are established by contrasts among phones in the inventory.

^c/sp- st- sk-/ are not true clusters, and therefore they pattern differently in typological markedness, speakers' psycholinguistic judgments, and children's learning in treatment. Treatment of these sequences has been experimentally shown to inhibit generalization learning (see Gierut, 1999; Gierut & Champion, 2001).

^dImplicational laws that pertain to phonological processes are formulated to reflect errors. This stands apart from all other implicational laws that are formulated in terms of accuracy and occurrence. Consequently, in laws involving processes, the markedness values are just the reverse, with the latter process being the crucial, more complex error to eliminate in treatment.

^eThis assumes that obstruents are phonotactically permissible in final position.

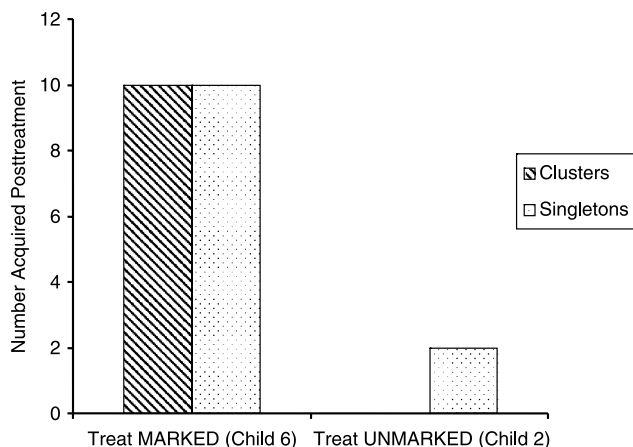
FIGURE 2. Posttreatment generalization, defined as percentage use in untreated probe items, following treatment of a marked cluster (Child 154) versus an unmarked affricate (Child 147).



sonorous classes are stops and affricates, followed by fricatives, nasals, liquids, and glides, with vowels being most sonorous. The closer two classes are to each other on this continuum, the smaller their sonority difference. Continuing in accord with the implicational law, the smaller the sonority difference, the more marked the cluster. What is especially interesting about this second law is that it establishes relative degrees of complexity among clusters. That is, whereas clusters are more marked than affricates (and also singletons), within the class of clusters, there is an additional range of relative complexity based on markedness.

FIG3 Figure 3 shows the results of the clinical application of this second law (Gierut, 1999). Child 6 (age = 3;8) was treated on

FIGURE 3. Posttreatment generalization, defined as number of new phonological properties acquired, following treatment of a marked cluster with a small sonority difference (Child 6) versus an unmarked cluster with a greater sonority difference (Child 2).



the cluster /bl-/, and Child 2 (age = 4;2) on the cluster /kw-/. The cluster /bl-/ has a smaller sonority difference than /kw-/ because, from the above continuum, the interval between stops and liquids is less than that between stops and glides. Thus, Child 6 was presented with more complex input in treatment of /bl-/ than was Child 2 in treatment of /kw-/, even though both children were taught clusters. As before, neither child produced target clusters prior to treatment. From the display, it can be seen that Child 6 showed greater generalization post-treatment. In all, 10 new clusters (/tw- kw- pl- bl- sw- fl- sm- sn- sp- st-/) were learned, representing the full range of sonority values of English. The treated cluster /bl-/ was produced with 60% accuracy in untreated probe words, and the 9 other untreated clusters were in the range of 40%–100% accuracy. This child showed further generalization to the singleton inventory, with improved production of 10 segments /f v T D s z tS h l r/ in the range of 6%–100% accuracy. In contrast, Child 2 showed no generalization to clusters, maintaining 0% accuracy in treated and untreated clusters. Nonetheless, this child generalized to two untreated singletons /S dZ/, with accuracy in the range of 12%–24%. (It should be noted that both children added affricates to their phonemic repertoire following treatment of clusters, albeit marked or unmarked, as a further instantiation of the prior lawful relationship between clusters and affricates.) As expected from the implicational law, the more complex treatment target as defined by sonority difference triggered greater generalization and change in the sound system.

Phonological Complexity and Learnability

Taken together, these illustrations of the generalization patterns that followed from treatment of marked structures are wholly consistent with the premises of learnability theory. As in typical development, language learning for children with functional phonological delays can be facilitated by the

presentation of complex input in treatment. This demonstration also underscores that children with functional delays are able to utilize complex input to advance their phonological systems, despite apparent linguistic lags. The course of typical development is thus mirrored in the clinical application of language laws. This notwithstanding, perhaps the most frequently asked questions about the clinical application of phonological complexity relate specifically to learnability theory; some of these are addressed below.

Do implicational laws predict the specific sounds that a child will learn? Laws are stated in terms of general sound classes, as are the predictions of generalization learning. Consider the prior example that if a child produces affricates, he or she will also produce fricatives. This law does not state which affricates or fricatives will be in the inventory, or how many of each will be acquired. The indeterminacy actually provides for variability among languages (and child grammars), consistent with complexity from a functional perspective. One clinical consequence though is that probes must be constructed to sample both sides of an implicational law in the plan for generalization learning. In this example, untreated affricates and fricatives should both be probed to document phonological gains due to markedness.

Will treatment based on complexity induce the expected benefits if a child already produces some but not all of the marked and unmarked sounds that are associated with a given law at baseline? By this description, the child's phonology apparently includes both the marked and unmarked properties of the law, like the grammar shown in Table 1 (third row). Consequently, if treatment were based on this particular law, it would not expose the child to new linguistic categories that lie outside of the existing subset grammar. This would be a case of providing the child with more of the same type of input. Borrowing from Piaget (1952), this treatment tack has been termed a *horizontal goal attack strategy* (Fey, 1986). It may be most appropriate when the clinical goal is to add new items to an existing category, as opposed to adding new categories themselves (Johnston, 1988). Following treatment of this type, the expected phonological gains will come in the form of "enhanced" performance (e.g., increases in accuracy of already known structures; Dinnsen & Elbert, 1984).

If a child is treated on a marked phonological property but does not generalize to this target and acquires instead only unmarked properties, is treatment based on complexity still considered effective? Here, the mistaken focus is on the apparent lack of generalization associated with the treated marked property. It is important to understand that, even in such cases, treatment provides a child with input that is more advanced than the existing subset grammar because the treated target is unknown, marked, and complex. This is consistent with a *vertical goal attack strategy* (Fey, 1986), which aims to establish new phonological categories (Johnston, 1988). The novel additions happen to be unmarked in this case, but nonetheless they represent an expansion of the subset grammar, in line with that shown in Table 1 (second row). Perhaps of most importance, the elaboration of the grammar is entirely predictable from higher order, governing relationships among sounds (Dinnsen, Chin, & Elbert, 1992). Structures that are added to the phonology are not random, haphazard, or accidental in the clinical application of implicational laws.

AQ2

AQ2

Consequently, generalization can be systematically planned for (instead of being "hoped" for) in the development of clinical treatment programs.

Can implicational laws be used combinatorially for an added effect on phonological learning? It is true that some of the tested laws shown in Table 2 are directly related. One rather elaborate chain involves clusters predicting affricates, affricates predicting fricatives, and fricatives predicting stops. This particular chained relationship has been borne out in the treatment literature, such that children who were taught clusters did indeed generalize to members of these other classes (Child 6 herein; also Gierut, 1999; Gierut & Champion, 2001). Children were exposed to complex input that was well outside of the range of their subset grammar. This, in turn, triggered a wave of other related (concentric) complexities, much like the expansion of grammar depicted in Figure 1. One suggestion is that the chained applications of implicational laws has the potential to induce the broadest expansion of the phonological system; however, it should be cautioned that the generalization effects have not been fully explored for all potentially overlapping laws.

Is there one ideal complex target that can be recommended for use in treatment of all children with functional phonological delays? This view is inconsistent with the notion of complexity at a functional level generally, and phonological complexity based on implicational laws specifically. This is because the laws that govern a system must also allow certain degrees of freedom in that system. Each child will present a unique phonology for treatment. Consequently, some implicational laws will be clinically relevant for use in expanding that child's sound system, whereas others will not because the latter may already be in place in the sound system. Therefore, it is important to carefully describe a child's phonological system at the epistemic level, determine which hierarchical aspects of the phonology (e.g., phones, phonemes, syllables, rules) warrant most attention at the ontological level, and then identify which laws are best suited to changing those aspects of the phonology at the functional level of complexity.

Is complexity the only factor that is relevant in designing treatment for children with functional phonological delays? Thus far, the available treatment efficacy research has focused on the structure of linguistic input in operationalizing phonological complexity. The reason stems from learnability theory, with its emphasis on linguistic input as the primary form of evidence that triggers language learning. In this way, the main goal has been to define the linguistic complexity of phonological structure; that is, what is it about the structure of language per se that is complex? This notwithstanding, it is possible for complexity to take a number of different forms, consistent with Rescher's (1998) definitions. We may find, for example, that linguistic complexity complements, or perhaps even contrasts with, "treatment complexity." For the future, it will be important to explore sources of complexity that may be related to the delivery or administration of phonological treatment. For instance, treatment complexity may be affiliated with the duration or intensity of phonological services. Here, some pertinent variables might include the role of massed practice, block scheduling, or "vacations" from treatment (e.g., Fey, Cleave, Long, & Hughes, 1993; Tyler & Figurski, 1994). As another example, the items used in treatment and the way

in which they are presented to a child may factor into a working definition of treatment complexity. These may encompass questions about the efficacy of real words versus nonwords, tabletop versus electronic displays, or the lexical properties of the input itself (e.g., a given word's frequency, its age of acquisition, or its relationship to other rhyming words in the language; Leonard & Ritterman, 1971; Martin & Gierut, 2004; Morrisette & Gierut, 2002; Shriberg, Kwiatkowski, & Snyder, 1989, 1990; Storkel, 2004; Tyler & Edwards, 1993). Moreover, the mode and timing of a clinician's input or feedback may further bear on treatment complexity. Some variables to take account of may include the relative importance of perceptual, imitative, productive, or metalinguistic information (Dean et al., 1995; Rvachew, 1994; Saben & Ingham, 1991). There is one word of caution however. It is possible that the variables associated with clinical assessment and treatment may not be systematically governed by principles of complexity in the same way that language is. This may be especially true in the cases of ontological and functional complexity, where a hierarchical and lawful connection between variables must be established. Nonetheless, the full effects of complexity have yet to be delineated but hold appealing possibilities for clinical practice and research.

Domain-General Extensions of Complexity

The clinical utility of phonological complexity may seem to be a counterintuitive strategy of instruction, despite its demonstrated efficacy. Moreover, it may appear that complexity is a language-specific construct given the complementary demonstrations in phonology, syntax, and semantics. In this final section, complexity is assigned a broader role as a possible general aid to learning of any type. A central question is whether other trajectories of development benefit from complexity. That is, are there lawful relationships that govern *nonlinguistic* systems, which can be manipulated in teaching situations so as to induce cascading effects on children's learning? If so, then this begins to identify new directions for future research.

One striking example comes from an experimental evaluation of Piaget's (1952) stages of operational thought. Recall that Piaget proposed six developmental stages to account for children's ability to conceptualize information, beginning with the most concrete and extending to abstracted, hierarchical classification (Inhelder & Piaget, 1964/1969). Like implicational laws of language, Piaget's stages of development outline the precursors to more complex cognitive operations. In a classic study, Kuhn (1972) manipulated Piaget's stages in a stepwise fashion, such that children either received instruction at the same (or simpler) stage as their baseline stage of cognitive development or were taught properties of more advanced cognitive stages. Two related findings emerged. First, children who were instructed at the same or developmentally simpler stage showed little to no advancement to more complex stages of operational thinking at posttesting. The lack of change associated with this form of instruction resembles that predicted by learnability theory when children are provided with input that is more of the same or less than their presenting subset grammar. A second finding was that children who received more advanced input showed gains in the

expected (more complex) direction. In the latter case, Kuhn viewed complexity of the input as the stimulant to children's progression through Piaget's stages but argued that complexity did not dictate the details of cognitive change. Like in language, the change that took place was child-specific, yet within the boundaries of Piaget's stages. Notice the parallel to implicational laws: Marked structures trigger predicted patterns of phonological generalization, but there are well-defined degrees of freedom in the extent and nature of change within and across children's sound systems.

This illustration of complexity in cognitive development points to a distinction that has been made between *domain-specific* versus *domain-general* systems (Kelly & Martin, 1994). Domain-specific systems are independent of, and unique from, other systems, whereas domain-general systems are interacting, related to, and perhaps even derivable from other systems. Domain differentiation has been at the heart of current debates on the origins of language; however, it appears that it may serve a positive purpose in shaping the direction of research on complexity. Because the construct of complexity is emerging as a general operating principle of learning and cognition, it can be characterized as a domain-general property. Yet, in order for complexity to be realized in language, a domain-specific approach must be adopted. Studies are needed to further discern which linguistic categories are complex, to isolate how they are complex, to determine the hierarchical and lawful relationships among such complex categories, and to experimentally test their relative efficacy as input for language learning. Thus, complexity may be revealed as a general mechanism common to all systems, but in order to determine how complexity is implemented in any one given system, it will be necessary to look to the details of that particular system. In this way, both domain-general and domain-specific approaches may emerge as mutually beneficial to an understanding of the process of language acquisition (see Hirsh-Pasek & Golinkoff, 1996, for a similar view).

In closing, the application of linguistic complexity in clinical treatment has its theoretical underpinning in learnability theory. As in typical language development, complex linguistic input induces positive effects on the grammars of children with functional phonological delays. Importantly, the cascading effects of complexity on learning broadly encompass developmental, clinical, linguistic, and cognitive domains, which lend further credence to the robustness of the construct.

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