

Clinical Forum

Complexity in Phonological Treatment: Clinical Factors

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Children with functional phonological disorders constitute a substantial portion of the caseload of speech-language pathologists employed in school settings. The National Institute on Deafness and Other Communication Disorders (1994) has estimated that 10% of children receive services to remediate errors in sound production that affect intelligibility. Reportedly, these children often have co-occurring linguistic and academic difficulties that ultimately may impact their overall scholastic success, so much so that they may not achieve their full potential (Felsenfeld, Broen, & McGue, 1992, 1994; Felsenfeld, McGue, & Broen, 1995). Moreover, there is evidence of a critical period for normalization of the sound system, which extends through approximately age 8:5 (years:months), with a leveling in learning observed beyond this age (Shriberg, Gruber, &

Kwiatkowski, 1994; Shriberg, Kwiatkowski, & Gruber, 1994). Given caseload demands, potentially handicapping risks, and the necessity of early intervention, treatment efficacy for children with functional phonological disorders becomes an increasingly critical issue.

Treatment efficacy has been defined in three interrelated ways with a distinction between effectiveness, effects, and efficiency (Olswang, 1990). *Treatment effectiveness* establishes whether a given treatment works. *Treatment effects* refer to the behavioral changes that occur following treatment. *Treatment efficiency* determines whether one treatment method is better than another. Of these three dimensions, treatment efficiency is perhaps the most important clinically; yet, for children with phonological disorders, it is an area that has received the least attention (Gierut, 1998 for review). Furthermore, the available comparative studies of different treatment methods have resulted in equivocal or conflicting results (Fey et al., 1994; Hoffman, Norris, & Monjure, 1990; Masterson & Daniels, 1991; Pollack & LaLonde, 1989; Powell, Elbert, Miccio, Strike-Roussos, & Brasseur, 1998; Saben & Ingham, 1991; Tyler, Edwards, & Saxman, 1987; Tyler & Sandoval, 1994; Tyler & Watterson, 1991; Ward & Bankson, 1989). This has prompted the suggestion that in order to obtain the greatest insights, it may be more informative to focus on *what* is being taught, rather than on *how* it is being taught. Thus, the key to treatment efficacy for phonological disorders may lie in the initial selection of target sounds for treatment.

In target sound selection, the ultimate goal is to induce the greatest phonological change or generalization in a child's sound system. *Generalization* may be defined as an extension or transfer of learning. In its most limited sense, generalization minimally affects the treated sound in untreated words or contexts. That is, treatment of a

ABSTRACT: The construct of complexity has been advanced recently as a potentially contributing variable in the efficacy of treatment for children with functional phonological disorders. Thus far, complexity has been defined in terms of linguistic and psycholinguistic structure, articulatory phonetic variables, and conventional clinical factors. The focus of this paper is on clinical complexity as it influences the selection of target sounds for treatment, with three clinical factors reviewed: consistency of the error, normative age of acquisition, and number of errors to be treated. The collective findings suggest that treatment of seemingly more complex targets results in greater phonological gains. These results are integrated with converging evidence from other populations and language and learning domains.

KEY WORDS: phonological disorders, treatment efficacy, generalization, complexity

fricative in a few representative words may improve production of that same fricative in other untreated words. Or, treatment of a fricative in initial position may result in improved production of that same fricative in intervocalic or final positions. The phonological property being treated is precisely that which improves, such that the extension of learning is only lexical or contextual in nature. This type of generalization has been dubbed “local” change because of its somewhat narrow impact on the sound system (Gierut, 1998). Other types of generalization affect a child’s sound system more broadly. These include within- and across-class generalization. *Within-class generalization* refers to a change in untreated sounds from the same manner class as the treated sound. Treatment of one fricative, for example, may lead to improvements in the production of other fricatives. Here, the extension of learning is to untreated but related members of a sound category. *Across-class generalization* refers to a change in untreated sounds from different manner classes than the treated sound. Continuing the example, treatment of that one fricative may further result in improvements in the production of affricates or liquids. The extension of learning in this case is to untreated and unrelated members of a sound category. Within- and across-class generalization are especially desirable treatment effects because they contribute to “global” changes in a child’s overall sound system.

Recent clinical research has revealed an intriguing, but perhaps counterintuitive, finding that bears on the selection of target sounds for treatment to promote global system-wide change. Specifically, treatment of more complex properties of the phonological system appears to result in the greatest generalization and change. This effect of complexity on learning has been shown to hold across converging studies, populations, and perspectives. Table 1 presents a summary of the representative literature.

For phonological disorders, the available research falls into four general categories: complexity as defined by linguistic structure, psycholinguistic structure, articulatory phonetic factors, and conventional clinical factors. Linguistic complexity has established that treatment of typologically more marked properties of language induces the greatest generalization. To illustrate, a study conducted by Dinnsen and Elbert (1984) showed that treatment of marked fricatives enhanced children’s production of fricatives and stops, whereas treatment of unmarked stops led only to gains in other stops. Therefore, broader change was observed following treatment of more complex marked fricatives.

Psycholinguistic complexity has focused on the characteristics of words that serve presumably to organize the lexicon for word recognition in perception and production. It has been shown that treatment of high-frequency words in language contributed to greater generalization and change in the sound system than did treatment of low-frequency words (Gierut, Morrisette, & Champion, 1999; Morrisette, 2000). This is consistent with dual processing models that posit lexical and sublexical levels of structure (Levelt & Wheeldon, 1994; Vitevitch & Luce, 1998, 1999). High-frequency words have been shown to be more complex at the sublexical level, which is associated with phonological units such as phonemes or features (Storkel &

Morrisette, 2001). Similar results have been obtained for articulatory phonetic complexity. For instance, treatment of nonstimulable sounds triggered generalization to non-stimulable and stimulable sounds. By comparison, treatment of stimulable sounds only prompted generalization to other stimulable sounds (Powell, Elbert, & Dinnsen, 1991). Again, greater change was induced following treatment of more complex nonstimulable sounds.

In this paper, the complexity associated with conventional clinical factors and its role in treatment efficacy for functional phonological disorders is examined. Three clinical factors that are used often to guide a clinician’s selection of target sounds for treatment are considered: consistency of the error, normative age of acquisition, and number of errors to be treated. The role of clinical complexity involving these factors has been reported previously in single-subject experimental manipulations of treatment. Consistent with the majority of research on treatment efficacy for phonological disorders, single-subject experiments have distinct advantages (Gierut, 1998; McReynolds & Thompson, 1986): They document patterns of generalization for individual children in light of heterogeneity in the population, they allow for within- and across-subject comparisons of treatment effects as evidence of local and global phonological change, and they demonstrate generalizability to the population at large through direct and systematic replications of treatment effects, such that different children may be treated on the same sound and also different children may be treated on different sounds to reveal similar outcomes. Generalizability of the findings is further obtained through replications across laboratories and populations, as summarized in Table 1.

In this article, we revisit the published single-subject literature that bears specifically on complexity as defined by these three clinical considerations in target sound selection. The focus is specifically on differential generalization that follows from treatment of sounds that are seemingly more versus less complex. It is asked whether greater phonological gains come about as a result of treating more complex targets or less complex targets. The aim is to identify those target sounds for treatment that achieve the optimal goal of system-wide generalization. For each clinical variable, the general research findings are described and illustrated with complementary data from individual children. The data to be presented have been extracted from the original reports and are exemplary of the systematic patterns of results that were obtained across children. The data have been plotted to reflect generalization accuracy only at the final posttreatment sample relative to a child’s pretreatment baseline performance; hence, only quantitative results are included. Select comparisons are among children who received the same number of pretreatment baselines to maintain the integrity of the single-subject designs. Children are identified by subject number only, and this was assigned in accord with the order of their enrollment in a particular study. The subject numbers reported herein are consistent with the original reports. The reader is referred to the primary sources for the complete presentation of longitudinal learning for individual children and for a description of the way in which treatment and

Table 1. Representative descriptive and experimental literature supporting the complexity of phonological targets.^a

COMPLEX TARGETS are..

Typologically MARKED PROPERTIES, i.e.,	Greenberg, 1978
CONSONANTS imply vowels	Robb, Bleile, & Yee, 1999
VOICED OBSTRUENTS imply voiceless obstruents	McReynolds & Jetzke, 1986
FRICATIVES imply stops	Dinnsen & Elbert, 1984
	Elbert, Dinnsen, & Powell, 1984
AFFRICATES imply fricatives	Ingram, Christensen, Veach, & Webster, 1980
	Schmidt & Meyers, 1995
LIQUIDS imply nasals	Dinnsen, Chin, Elbert, & Powell, 1990
	Dinnsen, Chin, & Elbert, 1992
	Tyler & Figurski, 1994
CLUSTERS imply singletons	Elbert & McReynolds, 1979
	Gallagher & Shriner, 1975
	Williams, 1986, 1988
TRUE CLUSTERS imply affricates imply singletons	Gierut & O'Connor, 2000
	Lleó & Prinz, 1997
LIQUID CLUSTERS imply a liquid contrast	Archibald, 1998
	Gierut & O'Connor, 2000
TRUE CLUSTERS WITH SMALL SONORITY DIFFERENCES imply clusters with greater differences	Broselow & Finer, 1991
	Eckman, 1991
	Eckman & Iverson, 1993
	Gierut, 1999
	Gierut & Champion, 2001
LATER ACQUIRED CLUSTERS imply early acquired clusters	Elbert, Dinnsen, & Powell, 1984
	Powell & Elbert, 1984
Sounds in HIGH-FREQUENCY WORDS	Gierut, Morrisette, & Champion, 1999
	Leonard & Ritterman, 1971
	Morrisette, 2000
Sounds in words from LOW-DENSITY NEIGHBORHOODS	Gierut, Morrisette, & Champion, 1999
	Morrisette, 2000
NONSTIMULABLE sounds	Dinnsen & Elbert, 1984
	Elbert & McReynolds, 1978
	Powell, Elbert, & Dinnsen, 1991
	Sommers et al., 1967
Sounds that are ACOUSTICALLY UNDIFFERENTIATED	Forrest, Weismer, Hodge, Dinnsen, & Elbert, 1990
	Kornfeld & Goehl, 1974
	Tyler, Edwards, & Saxman, 1990
	Tyler, Figurski, & Langsdale, 1993
	Weismer, Dinnsen, & Elbert, 1981
Sounds with more elaborated featural structure, i.e., LATERALITY and/or STRIDENCY distinctions	Beers, 1996
	Dinnsen, Chin, Elbert, & Powell, 1990
	Dinnsen, Chin, & Elbert, 1992
	Keske, 1996
	Tyler & Figurski, 1994
Sounds EXCLUDED FROM THE INVENTORY, i.e., consistently in error	Brière, 1966
	Gierut, Elbert, & Dinnsen, 1987
	Hammerly, 1982
	Hardy, 1993
	Williams, 1991
DEVELOPMENTALLY LATER ACQUIRED sounds	Dyer, Santarcangelo, & Luce, 1987
	Gierut, Morrisette, Hughes, & Rowland, 1996
	Powell, 1991
	Powell et al., 1998
TWO NEW SOUNDS paired in contrast to each other	Gierut, 1990, 1991, 1992
	Gierut & Neumann, 1992
Sound pairs that differ by MAJOR CLASS DISTINCTIONS	Gierut, 1990, 1991, 1992
	Gierut & Neumann, 1992
Sound pairs that differ by MAXIMAL FEATURE DISTINCTIONS	Gierut, 1989, 1990, 1991, 1992
	Gierut & Neumann, 1992
	Pereira, 1999

^a Complex targets are shown in capital letters.

feedback were delivered. The citations in Table 1 also should be consulted for additional replications of these reported effects.

CONSISTENCY OF ERRORS

A child's errors in the production of a target sound may be either consistent or inconsistent across words and contexts. Consistent errors are typified by 0% accurate productions in all relevant words and word positions. In these cases, a target sound is excluded from a child's phonetic and phonemic repertoires as characterized linguistically by phonotactic constraints (Dinnsen, 1984). Inconsistent errors, on the other hand, are associated with more variable productions whereby a target sound is produced accurately on some occasions in certain words or select word positions. Variable productions of this sort may be predictable by phonetic context as characterized linguistically by obligatory or optional phonological rules (Dinnsen, 1984). Variable productions also may be unpredictable with accurate productions emerging on a case-by-case basis through the process of lexical diffusion (Labov, 1981). To clarify, *lexical diffusion* is a gradual change in sound production that takes place on a word-by-word basis as opposed to an across-the-board change where all relevant words change in production at once. Relatively speaking, a child would be credited with more knowledge of those sounds that are produced inconsistently in error as compared to other sounds that are produced consistently in error. Inconsistent errors therefore are synonymous with "most phonological knowledge" and consistent errors with "least phonological knowledge" (Gierut, Elbert, & Dinnsen, 1987).

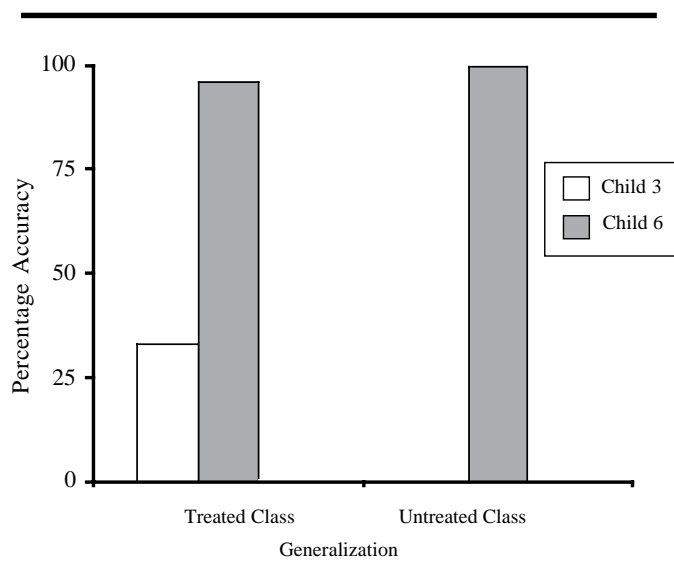
In target sound selection, inconsistent errors have been recommended conventionally as a starting point of treatment (Dyson & Robinson, 1987; Johnson, Brown, Curtis, Edney, & Keaster, 1948; Van Riper & Irwin, 1958). If a child already has some (albeit limited) knowledge of a sound, then treatment may be designed to capitalize on this: There is a modest base from which production accuracy may be extended. There also is an opportunity for positive feedback in treatment because some productions are likely to be correct. This potentially reduces any frustration a child may encounter in the learning task. In contrast, consistent errors may be a more complex starting point of treatment. In this instance, both phonetic and phonemic goals would need to be addressed. Articulatory placement must be established and stabilized, and the contrastive functioning of a sound in signaling meaning differences among morphemes must be demonstrated. A relevant question for treatment efficacy is "Which starting point of treatment ultimately leads to the broadest system-wide change?"

Gierut and colleagues (1987) explored this question using two groups of preschool children. One group of children began treatment with sounds of which they had most phonological knowledge, these being produced inconsistently in error. The other group of children began treatment with sounds of which they had least phonological knowledge, these being produced consistently in error.

Throughout treatment, generalization was monitored in order to trace gains in production accuracy. For both groups, generalization was sampled for sounds produced inconsistently and consistently in error. In this way, it was possible to determine the effects that teaching an inconsistent error had on other, consistent errors and vice versa. Stated another way, system-wide generalization from most-to-least knowledge and the reverse, least-to-most knowledge, could be documented.

The general findings revealed that treatment beginning with inconsistent errors (most knowledge) promoted change in the treated sound in untreated words and contexts, as well as within-class generalization. But, treatment of an inconsistent error had little to no effect on other untreated consistent errors of the sound system. Illustrative data from Child 3 of this study are shown in Figure 1. (Recall that a child's subject number corresponds to the order of enrollment in a particular study; hence, Child 3 was the third child enrolled.) For this child, treatment of the emerging sound /t/ resulted in improvements in this and other stops at the final posttreatment probe sample; however, there was no generalization to untreated fricatives that were produced consistently in error. Generalization thereby was limited to only the treated (i.e., inconsistent) class. In comparison, when treatment began with a sound that was consistently in error (least knowledge), there was generalization to the treated sound in untreated words and contexts, in addition to generalization both within and across classes. Children of this group evidenced global system-wide improvements such that treatment of a consistent error facilitated gains in accuracy of other consistent and inconsistent errors. Child 6 is a representative case shown in Figure 1. Treatment of /v/, excluded from this child's inventory across contexts, enhanced productions of other untreated sounds that were consistently and inconsistently in error.

Figure 1. Percentage generalization accuracy following treatment of inconsistent (open bar) versus consistent errors (hatched bar) as adapted from Gierut, Elbert, and Dinnsen (1987).



Overall, the results of this study demonstrated that local changes in a child's sound system are likely to occur following treatment of either inconsistent or consistent errors. This suggests that there is no necessary advantage to first teaching a sound that is emerging in a child's grammar, as has been recommended conventionally. The differential effects of treatment indicated that treatment of sounds that were consistently in error further induced broader generalization across the sound system. The seemingly more complex consistent errors thus surfaced as more efficacious treatment targets. A recommendation that emerges is to select sounds that are excluded from a child's repertoire for treatment. This recommendation has been employed in other clinical studies with replications of results as in Table 1.

Normative Age of Acquisition

Another factor that often is taken into account in setting target goals is the normative age of acquisition of a sound. Normative scales typically are obtained from cross-sectional studies of the accuracy of sound production by children of different ages. Smit, Hand, Freilinger, Bernthal, and Bird (1990) published the most recent and comprehensive of these reports, with corresponding recommendations for target sound selection, but they also cautioned against a strict reliance on normative scales to guide treatment. This notwithstanding, an appeal to normative ages of acquisition places the design of treatment within a developmental perspective. The underlying assumptions of this approach are that sounds are acquired in a fixed sequence, certain sounds are prerequisite for certain others, and the order of sound emergence corresponds with ease of learning (Winitz, 1969). As applied to phonological disorders, there is a further assumption that these children will mirror the path of normal acquisition when treatment invokes a developmental progression of sound learning (Elbert, 1984; Ingram, 1989; Leonard, 1992).

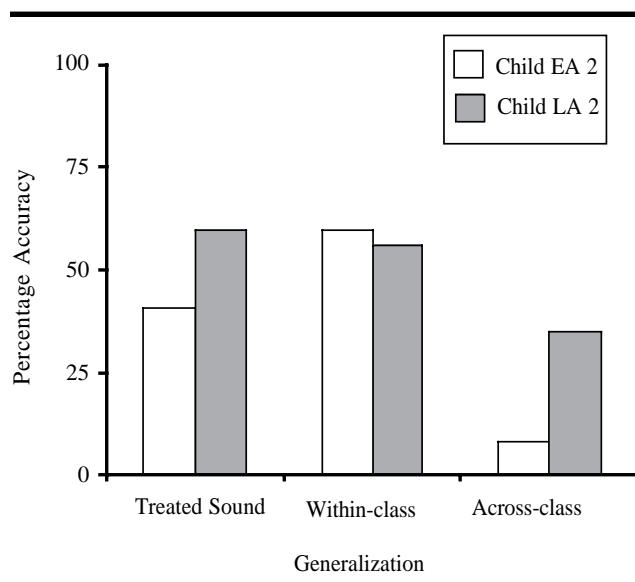
In the selection of sounds for treatment, developmentally earlier acquired sounds are recommended conventionally as potential targets (Dyson & Robinson, 1987; Van Riper & Irwin, 1958). Their emergence at a developmentally early age presumably signals their ease and prerequisite status for building the phonological system. Later acquired sounds are considered the more complex targets. Yet, because there is well-documented individual variability associated with sound learning (e.g., Ingram, Christensen, Veach, & Webster, 1980; Vihman, Ferguson, & Elbert, 1986), it is suggested that children may acquire the sounds of language in unique ways and orders. For treatment efficacy, a relevant question is "Does treatment of early versus later acquired sounds result in broader system-wide change?"

This question was examined in a comparison of the effects of teaching two groups of preschool children early versus later acquired sounds (Gierut, Morrisette, Hughes, & Rowland, 1996). The sound selected for treatment was classified as early (or late) relative to each child's chronological age; this was in contrast to absolute rankings of early-, mid-, and late-8 sounds (cf. Shriberg, 1993). For example, using the Smit et al. (1990, p. 795) data, /ð/

would be considered early acquired for a 5-year-old girl, but later acquired for a boy of the same age. The reason is that, by this normative scale, /ð/ is to be mastered by girls at age 4:6 and by boys at age 7:0. In this study, the sounds selected for treatment, whether early or later acquired, were produced consistently in error by the children with 0% baseline accuracy, following the aforementioned recommendation for target sound selection. Throughout treatment, learning was measured with respect to the treated sound, within-class generalization, and across-class generalization as a reflection of local and global phonological changes in children's sound systems.

The general findings indicated that all children generalized to the treated sound, regardless of its normative age of acquisition. Treatment of an early acquired sound led to improvements in production of that sound in untreated words and contexts; the same was true of treatment of a later acquired sound. Early and later acquired sounds therefore were comparable in inducing local change. Early and later acquired sounds also were on par with each other in terms of within-class generalization. Both kinds of treatment targets promoted gains in production accuracy of other untreated sounds from the same manner class. These two findings are illustrated in Figure 2 for Children EA2 and LA2, who were treated on early and later acquired targets, respectively. The posttreatment data for Child EA2 indicated that the early acquired treated target /g/ and other untreated (within-class) stops evidenced generalization. Similarly, for Child LA2, treatment of later acquired /θ/ triggered improvements in this and other untreated (within-class) fricatives. Thus, treatment of early and later acquired sounds appeared to be similar in their impact on generalization to treated and untreated sounds within the same manner class.

Figure 2. Percentage generalization accuracy following treatment of early acquired (open bar) versus later acquired sounds (hatched bar) as adapted from Gierut, Morrisette, Hughes, and Rowland (1996).



Differential effects of treatment were observed, however, in terms of across-class generalization. Children who were treated on a later acquired sound evidenced substantial changes in other untreated sounds from different manner classes, whereas those treated on early acquired sounds did not. Figure 2 illustrates this for Child LA2, who was treated on a later acquired sound and achieved near 40% across-class generalization accuracy. In the same display, Child EA2, who was treated on an early acquired sound, showed less than 8% generalization accuracy across class. Child LA2 thus showed broader system-wide gains. A core difference then between early and later acquired targets was associated with across-class changes in the sound system.

All in all, these results indicate that local and within-class change are likely to occur following treatment of either an early or a later acquired sound. As in the previous study, there is no necessary advantage to first teaching a sound that is early acquired, as is recommended typically. In fact, broader system-wide improvements resulted from treatment of later acquired sounds such that developmentally more complex sounds emerged as more efficacious treatment targets. The recommendation that follows is to select sounds for treatment that are later acquired. These results have been replicated in a within-subject normative comparison whereby given children were treated on both an early and a later acquired sound in error (Gierut et al., 1996). Also, the advantage of later acquired targets has been demonstrated in other experimental treatment comparisons including, for example, later acquired fricatives relative to early acquired stops (Dinnsen & Elbert, 1984; Elbert, Dinnsen, & Powell, 1984) and later acquired clusters relative to early acquired clusters (Elbert et al., 1984; Powell & Elbert, 1984).

NUMBER OF ERRORS TREATED

A final clinical factor concerning complexity is the number of error sounds or patterns to be targeted as the treatment goal. This is an issue that bears on establishing goal attack strategies in treatment. Fey (1986) defined a goal attack strategy as an approach to organizing treatment so as to facilitate the interruption of a child's errors and to aid in the subsequent reorganization of the sound system. Two general goal attack strategies have been described (cf. Piaget, 1960). A *horizontal goal attack strategy* isolates several sounds or patterns to be taught in sequence for predetermined periods of time. Cycles (Hodson & Paden, 1991) is an example of a treatment protocol that employs a horizontal strategy of setting treatment goals. In comparison, a *vertical goal attack strategy* aims to remediate a single sound or pattern until a predefined criterion of mastery is achieved. Traditional treatment as described by Van Riper (Van Riper & Irwin, 1958; Winitz, 1975) relies on a vertical goal attack strategy. Key differences between these strategies lie in the number of patterns being targeted and the criterion for advancement being time- or performance-based. The strategies are similar in that errors typically are targeted sequentially. By extension, consider

that it also is possible to vary the number of targeted sounds or patterns that are introduced simultaneously as treatment goals (cf. Elbert & Gierut, 1986; McCabe & Bradley, 1975). Although the relative efficacy of a horizontal versus a vertical goal attack strategy has not been evaluated widely (Tyler et al., 1987), there have been evaluations of the simultaneous presentation of single versus multiple targets in treatment. A majority of these studies have been conducted within the framework of minimal pair treatment.

By way of background, a *minimal pair* is defined as two words that differ by one sound for purposes of signaling a meaning difference among morphemes. In minimal pair treatment, a child is presented with such forms to reduce the occurrence of homonymy, illustrate the contrastive function of sounds in language, and enhance the interpretability of the message in communication (Fey, 1992). Interestingly, the way in which the contrasts of a minimal pair may bear on a child's phonological system in treatment is multifaceted. Consider that a child may be presented with minimal pairs that contrast a target sound with a corresponding sound that is the child's substitute. This is the setup of conventional minimal pair treatment (Weiner, 1981). To illustrate, a pattern of stopping may invoke the pair *sew—toe*, teaming the target fricative /s/ with its corresponding stop substitute [t]. Another way that minimal pairs may be used in treatment is by pairing a target sound with another sound that the child already uses correctly, as in maximal opposition treatment (Gierut, 1989). Continuing the example of stopping, the pair in this arrangement might be *sew—no*, where target /s/ is coupled with an accurate sound /n/, thereby avoiding any focus on the child's substitutions. Still another minimal pair option is to avoid any explicit reference to a child's presenting sound system at all. Rather, the child would be confronted with two contrastive sounds that are excluded from the repertoire (Gierut, 1989). In this scenario, a stopping error may be aligned with another error such as liquid gliding, with a potential minimal pair being *sew—row*. In this case, neither the fricative /s/ nor the liquid /r/ would be present in the child's inventory, thereby capitalizing on later acquired sounds that are produced consistently in error. In the selection of sounds for treatment, a relevant question is "Which minimal pairing promotes greater phonological change?"

To address this question, the collective results of four clinical treatment experiments were evaluated to determine the efficacy of teaching one new sound paired with its substitute, one new sound paired with a known sound, and two new sounds paired with each other (Gierut, 1990, 1991, 1992; Gierut & Neumann, 1992). Notice that the former pairings introduce only one new sound in treatment, whereas the latter pairings concurrently introduce two new sounds. At the heart of these comparisons is whether treatment goals should be established to target one error at a time or, alternatively, whether more than one error might be treated simultaneously as a presumably more complex goal. Each of the studies to be summarized involved a within-subject comparison within the framework of an alternating treatments design (McReynolds & Kearns, 1983). This design is tailored specifically to evaluate the

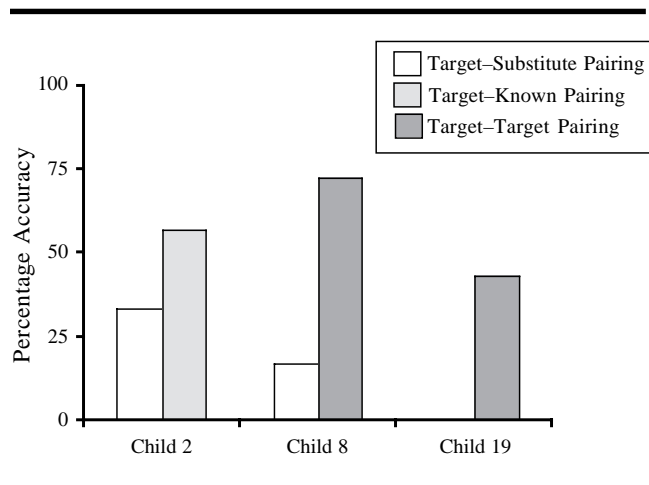
effectiveness of two different teaching conditions, in this case, different types of minimal pairings. Within this design, treatments are ordered randomly and alternated across sessions, with potential multiple treatment interference being controlled systematically (cf. Gierut, 1992, pp. 1052–1053). The premise is that a child will differentiate between the treatments and respond preferentially to one as opposed to the other as based on generalization. In our studies, generalization to the treated sound(s) in untreated words and contexts was monitored as a reflection of local change. Global changes across children's sound systems were described qualitatively in terms of expansion of the inventory; consequently, within- and across-class generalization will not be reported herein from quantitative perspectives (for qualitative data, the reader is referred to the original reports). As before, children's subject numbers correspond to their order of enrollment as in the published results.

Across studies, the general findings supported a continuum of treatment efficacy involving minimal pairs. Beginning with a first comparison, treatment of a target–substitute pair was evaluated relative to a target–known sound pair (Gierut, 1990). Results indicated that generalization in the target–known sound condition was as good as or better than that in the target–substitute condition: Children showed greater changes in the treated sound in untreated words and contexts, in addition to qualitative inventory expansion within and across classes. A representative case is Child 2, who received treatment on /ð/ paired with /t/ in a target–substitute correspondence versus /k/ paired with /m/ in a target–known sound correspondence. As the data in Figure 3 indicate, there was greater posttreatment accuracy in production of the treated sound paired with a known sound. Thus, greater local change was observed in treatment of a target–known sound pairing, which is consistent with a maximal opposition format (Gierut, 1989).

In a second set of comparisons, treatment of a target–substitute pairing was evaluated relative to a target–target pairing where two new sounds were introduced simultaneously (Gierut, 1991; Gierut & Neumann, 1992). Results showed that treatment of two new sounds paired with each other led to greater production accuracy, as illustrated for Child 8 in Figure 3. This child was treated on the target /ð/ and its substitute /f/ versus two other sounds, /dʒ/ and /z/, that were excluded from the inventory. As shown, greater generalization to the new target–target pairing took place. This replicates the prior effect whereby a target–substitute pairing was less effective. It also supports a treatment goal that simultaneously introduces two new sounds as opposed to one.

In a final comparison, a target–known sound pairing was manipulated relative to a target–target pairing of two new sounds (Gierut, 1992). As before, the target–target pairing emerged as more effective in promoting local change in the sound system (see, however, Study 2 of Gierut, 1992, pp. 1057–1061). Posttreatment production accuracy of the treated sounds in this condition was better than that in the target–known sound pairing. In Figure 3, data from Child 19 illustrate these effects. This child was taught the sound pair /dʒ/ and /ð/ in the target–target

Figure 3. Percentage generalization accuracy following minimal pair treatment variations as adapted from Gierut (1990, 1991, 1992; Gierut & Neumann, 1992).



condition, with each sound of the pair being phonologically unknown and consistently in error. In the alternate minimal pair condition, the child was taught /v/ in contrast to a known sound /t/. It can be seen that gains were made in the target–target pairing, but there was no generalization observed in the target–known sound condition. This provided a further replication of the benefits of simultaneously teaching two new sounds in treatment involving minimal pairs.

Taken together, these studies demonstrated that all three types of minimal pair comparisons resulted in generalization, but with relative degrees of effectiveness. On a continuum, pairing two new target sounds was more effective than a target–known sound pairing which, in turn, was more effective than a target–substitute pairing (Gierut, 1992, p. 1060). For treatment efficacy, these data imply that the simultaneous treatment of more than one target sound leads to greater change in the phonological system. A corresponding recommendation is to treat two sounds or error patterns in combination as a more complex treatment goal. On the one hand, this might not seem to be too surprising a recommendation because twice as much information about the sound system would be introduced in treatment; on the other hand, this is not the conventional incremental tack that often is taken when setting treatment goals (Bernhardt & Stemberger, 2000; Kearns, 1986). It also should be noted that this recommendation derives only from comparisons of minimal pairs, and it is not yet known whether other forms of treatment will lend similar conclusions.

QUESTIONS CONCERNING CLINICAL COMPLEXITY

In this paper, three clinical factors that bear on complexity in phonological treatment have been considered. The collective findings point to the selection of sounds for

treatment based on a consistent error, later acquired sound, and two new sounds paired with each other. In each of these cases, the presumably more complex treatment target triggered the greatest generalization. Although these findings present a novel alternative to the establishment of treatment goals, a number of questions remain concerning clinical complexity and its effect on learning. In this section, some clinical research needs are outlined.

It should be recognized that there are a host of factors that clinicians routinely take into consideration when selecting target sounds for treatment that extends beyond the three considered here. Powell (1991, p. 22) cited 22 variables of relevance in the clinical decision-making process. These included, for example, consistency of substitutions, stimulability, visual cues to sound production, frequency of sounds in language, and salience of sounds to a child in daily interactions. Of these, only substitutions and stimulability have been evaluated in terms of complexity and learning (Forrest, Dinnsen, & Elbert, 1997; Powell et al., 1991). Clinical research must continue to explore a full range of clinical factors and the role that complexity may play in target sound selection.

Clinical research also is due to establish potential additive and/or precedence relationships among variables associated with clinical complexity. Thus far, the role of complexity has been established in independent manipulations of clinical variables, but it may be that combinations of variables will result in multiplicative gains. For example, one prediction from this review might be that treatment of consistent errors involving two or more later acquired sounds will be three times as effective as treatment based on any one of these factors alone. The effects of all logically possible combinations of clinical variables should be considered in terms of complexity. In a related vein, precedence relationships among complexity variables have not been isolated either. It is not known yet whether one complexity factor is more important than another. Perhaps certain factors will emerge as higher order in target sound selection. Alternatively, it may be that some complexity variables will cancel each other, leading to little or no generalization from treatment (cf. Gierut et al., 1999). These issues, too, are open-ended.

The overlay of complexity onto various approaches to treatment is another outlet for continued investigation. The available complexity studies have used traditional or minimal pair approaches to treatment. An important question is whether clinical complexity will have a different outcome if other teaching paradigms, such as modified cycles (Hodson, 1997), metaphon (Howell & Dean, 1994), paired stimulus (Weston & Irwin, 1971), or whole-language (Norris & Hoffman, 1990) treatments, are employed. Finally, the phonological profile of a given child may lend itself differentially to clinical complexity. Perhaps a given child's presenting sound system will respond more (or less) positively to treatment that is based on complexity of the target. There is preliminary evidence to suggest that this may be the case (Gierut, 1992; Gierut & Champion, 2001; Powell & Elbert, 1984), but the specific ways in which a child's sound system enhances or constrains complexity need to be examined more thoroughly.

COMPLEXITY BEYOND PHONOLOGICAL TREATMENT

A final and critical question is whether complexity applies more broadly to other populations or domains of language and learning. Parsonson and Baer (1978) urged that the identification of such basic variables that cross cut areas and fields "provides the impetus for the development of an area of scientific inquiry" (p. 114). In this regard, the construct of complexity is especially intriguing because there have been a number of extensions of complexity to other arenas.

In normal development, complexity has been demonstrated to facilitate syntactic and semantic acquisition in first-language learning (Roepers & de Villiers, 1992). For example, Au and colleagues (Au, 1990; Au & Laframboise, 1990; Au & Markman, 1987) found that teaching a child color terms was facilitated when two novel colors were contrasted with each other (e.g., *ecru* paired with *puce*), as compared to contrasts between a novel color and its substitute label (e.g., *ecru* paired with *white*) or another known color (e.g., *ecru* paired with *red*). Notice that this finding on the use of complex contrasts in semantics is in striking parallel to the results reported for phonology. Perhaps contrasts will play an enhancing role in language learning, no matter the domain—phonology, semantics, or syntax.

In areas of normal development outside of language, researchers have found that infants' ability to reach for objects in space is enhanced when the learning environment requires a response that is developmentally beyond the baby's current skill level (Smith & Thelen, 1993; Thelen & Smith, 1994 and references therein). Similar findings have been obtained for other motor skills like stepping and walking. For school-aged children, complexity has been introduced as a philosophy of classroom instruction (Gagné, 1977). In tests of this teaching approach, most notably in the area of mathematics (Yao, 1989), it has been shown that teaching division first facilitated children's mastery of multiplication, subtraction, and addition. Teaching addition first did not yield the same results.

In fully developed systems, there have been further demonstrations of the effects of complexity on second-language instruction in the areas of phonology, morphology, and syntax (e.g., Eckman, 1977, 1985; Eckman, Bell, & Nelson, 1988; Gass, 1979; Hyltenstam, 1984). The phonological results obtained from second-language research closely parallel those obtained from research on children with functional phonological disorders. This is particularly evident in terms of typological markedness, whereby teaching second-language learners more marked properties of the sound system has resulted in greater production accuracy (Archibald, 1998; Broselow & Finer, 1991; Eckman & Iverson, 1993; Hawkins, 1987). For this population, too, teaching sounds excluded from the repertoire (~least knowledge) has contributed to systematic phonological gains (Hammerly, 1982; Hardy, 1993). In acquired language breakdowns in adults, there is additional evidence to support the role of complexity in learning. Thompson and colleagues (Ballard & Thompson, 1999;

Thompson, Ballard, & Shapiro, 1998; Thompson & Shapiro, 1995; Thompson et al., 1997; Thompson, Shapiro, & Roberts, 1993; Thompson, Shapiro, Tait, Jacobs, & Schneider, 1996) have shown, for example, that when adult aphasic patients received treatment on syntactically more complex constructions, they generalized to simpler constructions, but not vice versa.

Moving beyond language, there is supportive evidence of complexity in motor skill learning by adults, particularly as it relates to the conditions of practice (Schmidt & Lee, 1999). The relevant research examines motor skills involved in sports such as archery, golf, tennis, or skiing. The findings in this arena show that practice of more difficult skills or levels of a skill results in greater learning. This is very similar to the curricular approach advanced by Gagné (1977), noted above for children. Furthermore, training a motor skill as a whole and coordinated assembly of tasks has been shown to be more effective in learning than training incremental components of the skill. In other words, the presumably more complex whole is better than the sum of its simpler parts in motor skill learning.

Interdisciplinary research perspectives involving children and adults thus appear to converge on the construct of complexity as facilitative of learning. From this, it is possible to advance a strong form of a more general hypothesis concerning complexity. Namely, complexity may be the fundamental way in which the human mind acquires, learns, processes, or retrieves information. This is provocative because it suggests that complexity may be a reflection of cognition (Rescher, 1998). If true, then the real task at hand is to define the construct of complexity operationally and to establish its upper and lower bounds within each of a variety of domains. For the domain of phonology in particular, this will require an interdisciplinary approach that melds linguistic theories with theories of learning. Linguistic theories offer testable hypotheses about which structures of the sound system may be more or less complex. The possibilities span a full range of structures including, for example, features (Rice & Avery, 1995), segments (Stoel-Gammon, 1985), syllables (Gierut, 1999; Gierut & Champion, 2001), or stress (Kehoe, 1998). For any one of these, a core set of elements likely will emerge to define the parameters of phonological complexity. However, linguistic theories must describe not only sound structure, but also how that structure might be acquired (Chomsky, 1999). This has been especially challenging in light of two competing issues: Common patterns must be balanced against individual differences in sound learning, and phonological gains that occur at one point in time must accord with subsequent longitudinal change (Ferguson & Garnica, 1975). It is in this regard that theories of learning are of assistance because they provide the testing ground for validation of linguistic hypotheses. Through experimental manipulations, it will be possible to document which of the purported parameters of complexity may be reflected most generally in children's learning. Moreover, learning successes (and also failures) will in all likelihood provide the needed evidence to establish potential constraints on complexity. Linguistic theories thus offer the hypotheses that theories of learning, in turn, validate. When used in

tandem, theories of language and learning hold mutual power in confirming or falsifying phonological complexity. Yet, phonology is just one of many arenas in which complexity has been shown to be operative in learning. Through parallel and continued interdisciplinary study across domains, scientists ultimately may come closer to understanding how the mind functions within the framework of basic and applied cognitive sciences.

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