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Evidence-based practice: A matrix for predicting phonological generalization

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Abstract

This paper describes a matrix for clinical use in the selection of phonological treatment targets to induce generalization, and in the identification of probe sounds to monitor during the course of intervention. The matrix appeals to a set of factors that have been shown to promote phonological generalization in the research literature, including the nature of error patterns, implicational universals, developmental norms, and stimulability. A case study of a child with a phonological disorder is presented to illustrate how the matrix may be utilized in evidence-based practice. The matrix serves as a demonstration of how the translation of research to practice may be accomplished.

Keywords

Phonological disorders; phonological treatment; generalization; evidence-based practice

Introduction

Evidence-based practice has become an accepted framework in the diagnosis and treatment of speech, language, and hearing disorders in research and clinical settings (Dollaghan, 2007). On the research side, the push to identify the conditions that promote language learning has resulted in a number of principles (e.g. McReynolds, 1972; Shelton and McReynolds, 1979; Dinnsen and Elbert, 1984; Elbert, Dinnsen, and Powell, 1984; Elbert, Powell, and Swartzlander, 1991; Tyler and Sandoval, 1994; Gierut, 2001) and methods (e.g. Weiner, 1981; Koegel, Koegel, and Ingham, 1986; Dean, Howell, Waters, and Reid, 1995; Miccio and Elbert, 1996; Ingram and Ingram, 2001) that are prime for extension to clinical settings. One challenge, however, lies in the translation of published research findings to clinical application. While advances are widely disseminated, parallel demonstrations of the ways in which the empirical results may be interpreted, extended, or used as the foundation for efficacious practice are often missing in the literature. This was one aim that our colleague, Adele Miccio made a priority as part of her contributions to the field. The willingness and interest in explaining diagnostic and treatment innovations to practicing clinicians is clearly demonstrated in the breadth of Miccio's work, which encompassed, for example, phonological disorders (Miccio and Ingrisano, 2000; Miccio, 2002; 2005), stimulability (Miccio and Elbert, 1996), otitis media (Miccio, Yont, and Vernon-Feagans, 2002), bilingualism (Miccio, Hammer, and Toribio, 2002), Down's syndrome (Hewitt, Hinkle, and Miccio, 2005), specific language impairment (Yont, Miccio, and Hewitt, 2002),

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literacy (Hammer and Miccio, 2004), and pragmatics (Vernon-Feagans, Miccio, and Yont, 2003).

The purpose of the present paper is to follow in that spirit by forging links between experimental clinical research and applied clinical intervention to better enable evidence-based practice. In this paper, we describe a generalization matrix that may be used clinically in the selection of treatment targets for children with functional phonological disorders. The matrix draws upon the findings of experimental clinical research in identification of 'optimal' treatment targets; namely, those sounds that are predicted to induce the greatest system-wide generalization to treated and untreated sounds and contexts. The paper is organized as follows: first, a brief review of the efficacy literature used in conceptualization of the matrix is presented. This is followed by a description of the matrix itself to show how various pieces of efficacy evidence are incorporated into its format. Then, a clinical case drawn from Miccio (1995) is introduced and the matrix of generalization applied in illustration of how treatment targets are selected and corresponding probe sounds are identified. The paper closes with consideration of future applications.

Efficacy base

The matrix of generalization incorporates findings from four strands of experimental treatment research: the nature of error patterns, implicational universals, developmental norms, and stimulability. These were identified because, for each, there are empirical data to support specific patterns of phonological generalization that follow from treatment. These patterns served as the basis for the predictions of generalization that derive from the matrix.

Error patterns

Linguistic analyses of children's phonological systems have provided insight into the range and source of various error patterns observed in typical and disordered development (Hodson and Paden, 1981; Edwards and Shriberg, 1983; Stoel-Gammon and Dunn, 1985; Ingram, 1989). This line of investigation has also led to recommendations about which errors, when treated, may result in the greatest system-wide phonological generalization (McReynolds and Elbert, 1981; Dinnsen and Elbert, 1984; Powell and Elbert, 1984; Elbert and McReynolds, 1985; Dinnsen and O'Connor, 2001). The evidence has shown that sounds excluded from a child's phonemic inventory may be optimal targets for treatment (Dinnsen, 1984; Gierut, Elbert, and Dinnsen, 1987). Linguistically, sounds excluded from the phonemic inventory are banned from a child's grammar and, also, from his/her lexical representations of words, due to the application of context-free phonotactic constraints. Behaviourally, this translates to that class of sounds that is produced with 0% accuracy in all relevant words and contexts. Studies have shown that treatment of sounds excluded from the inventory have positive benefits, which include the addition of new sounds to the inventory, the use of known sounds in new words and word positions, and a reduction in the use of phonological rules (Gierut et al., 1987). This approach contrasts with treatment of sounds in error that are produced with some degree of accuracy, where the learning is more localized, affecting phonological rules, but not also inventory structure or breadth of contextual use. In light of the evidence, the matrix of generalization assigns priority to sounds produced with 0% baseline accuracy across word positions and exemplars, with these being relatively more efficacious treatment targets.

Implicational universals

Numerous treatment studies have demonstrated the positive effects that obtain from appealing to implicational universals (laws) of language in the selection of treatment targets. Overview summaries and clinical applications are available (Ferguson, 1977; Greenberg, 1978; Ohala, 1980; Dinnsen and Elbert, 1984; Hawkins, 1987; Gierut, 2007). Briefly,

implicational universals describe co-occurrences among sound properties in language, such that the occurrence of one property is predictive of another. This is conventionally stated as X implies Y, but not vice versa. The clinical relevance of implicational laws is 2-fold. First, treatment of the implying property (X) predictably results in gains in the implied property (Y), without direct intervention (Dinnsen and Elbert, 1984; Gierut, 2007). That is, treatment of X results in generalization to X and Y; whereas treatment of Y leads to changes only in Y. Second, distinct implicational laws may be chained to capture a cascade of generalization effects, as illustrated below.

The matrix of generalization appeals to five implicational universals to capitalize on the efficacy effects in selection of a treatment target; these are listed in Table I. The phonological property shown in the left column is predictive of that shown in the right. For example, fricatives predict stops; hence, fricatives are given priority in the matrix in the selection of treatment targets to promote phonological generalization. Continuing, affricates predict fricatives, and therefore this class also assumes priority in the treatment target selection. For completeness, and following from Table I, voiced obstruents (i.e. stops, fricatives, affricates), liquids, and the pairs of sounds /s θ/, /z ð/, and/or /l r/ are each given priority in the selection of treatment targets using the matrix. Finally, notice the opportunity for chaining certain implicational universals (Gierut, 2007), namely those involving the fricatives and affricates. Because affricates imply fricatives, and in turn, fricatives imply stops, affricates hold potential to induce broad phonological generalization to all obstruents. This chained relationship too is incorporated into the matrix, with preferential weighting of affricates.

Developmental norms

Normative considerations associated with order of sound acquisition are also considered in the matrix. Efficacy data (Tyler and Figurski, 1994; Gierut, Morrisette, Hughes, and Rowland, 1996) have shown that treatment of later acquired sounds results in system-wide phonological gains, with generalization to the treated sound, and also to untreated sounds of the same and different manner class as the sound being treated. That is, the scope of learning encompasses the treated sound, within-class generalization, and across-class generalization, respectively. By comparison, treatment of earlier acquired sounds resulted in treated sound generalization (Rvachew and Nowak, 2001) and within-class generalization (Gierut et al., 1996). Across-class generalization, however, has not been observed following treatment of earlier acquired sounds. Thus, a preferred treatment target that promotes the broadest phonological generalization is a sound that is later acquired. As incorporated into the matrix, the late-8 sounds /θ ð s z ʃ ʒ l r/ (Shriberg, 1993) are preferentially weighted as more efficacious treatment targets.

Stimulability

Another factor that is incorporated into the matrix is the stimulability of treatment targets. Stimulability is a conventional consideration in target sound selection (Powell, 1991), and recent efficacy literature continues to support this variable as relevant to children's phonological generalization (Powell, Elbert, and Dinnsen, 1991; Powell and Miccio, 1996; Powell, Elbert, Miccio, Strike-Roussos, and Brasseur, 1998; Rvachew, Rafaat, and Martin, 1999). Stimulability probes and treatment programmes have also been established as efficacious, and particularly well suited for very young children with small phonetic inventories (Miccio and Elbert, 1996; Tyler, 1996). In all, the available evidence supports treatment of non-stimulable sounds that a child fails to imitate following a model, instruction, and/or demonstration (Powell et al., 1991). With respect to generalization, treatment of non-stimulable sounds has been shown to promote accurate production of non-stimulable and stimuable sounds, whereas treatment of stimuable sounds extended

accuracy only to stimulable sounds (Powell et al., 1991; Miccio and Elbert, 1996). Given this, the matrix of generalization gives preference to non-stimulable sounds in the selection of targets for treatment.

Overview of the matrix

The matrix of generalization is shown in Figure 1. At the top, forming the columns are sounds that will be considered as potential treatment targets. Following from the efficacy evidence summarized above, the potential treatment targets will include those sounds that a child produces with 0% accuracy across contexts during baseline testing. Notice further that the potential treatment targets are arranged by developmental order of sound acquisition, with /θ ð s z ʒ ʒ l r/ grouped together as the late-8, /ŋ t k g f v dʒ tʃ/ as the mid-8, and /m n p b d w j h/ as early-8 sounds. This allows normative considerations to be factored into the selection of potential treatment targets.

The rows of the matrix identify the target sounds that are predicted to generalize. These will be all of the sounds that a child produces in error that are of clinical relevance, as identified in the pre-treatment assessment or on phonological probes. Notice that, on the matrix, the sounds that make up the rows are arranged in conventional place-voice-manner format, beginning with the most anterior targets and moving to posterior by manner of articulation. The rows of the matrix will inform the clinician about those sounds in error that should be probed for generalization. This will be based on the predictions that derive from implicational universals.

In this regard, the implicational relationships shown in Table I are coded in the intersection of the columns and the rows of the matrix using bullet notation. Specifically, if an implicational relationship applies, this is noted by one bullet in the intersecting cell. If two implicational laws apply, then there are two bullets in the cell, and so on. For example, consider the intersection of column /f/ with row /p/. It can be seen that there is one bullet in the intersecting cell. This is due to the implicational relationship between fricatives and stops that is reported in Table I. Namely, the occurrence of a fricative (e.g. /f/) predicts the occurrence of a stop (e.g. /p/). Thus, if /f/ were treated (column), then /p/ (row) would be predicted to improve without direct instruction. Consequently, /p/ would be identified as one sound to monitor and probe for change based the prediction of generalization.

There is another diamond notation coded in the intersection of columns and rows of the matrix. The diamond is used to denote change associated with a sound that is treated. For example, column /f/ as it intersects row /f/ is to be interpreted as treatment of /f/ promotes change in /f/. A diamond is thus used when the same sound is in a given column and also it's intersecting row.

Near the bottom of the matrix, there is place to sum information, along with other abbreviated notations DEC, SEC, and PEC, which reference three forms of 'extra credit'. DEC refers to 'developmental extra credit', and captures the advantage associated with treatment of later acquired sounds. Notice that one extra point has been pre-entered into the matrix in the row labelled DEC for all sounds in the late-8 category. SEC defines 'stimulability extra credit', with one extra point going to all non-stimulable sounds, as would be identified in the pre-treatment assessment. Finally, PEC refers to 'phonetic extra credit', which is given to certain pairs of sounds—/s θ/, /z ð/, and/or /l r/—because of their phonetic advantage. These specific pairs are significant because they predict changes that cross-cut the entire sound system, as cited in Table I. The prediction is that treatment of a stridency distinction, either /s θ/ or /z ð/, or a laterality distinction /l r/ promotes changes in all other sound classes (Dinnsen, Chin, Elbert, and Powell, 1990; Dinnsen, Chin, and Elbert, 1992). To capture this, one extra credit point will be assigned when a child's pre-treatment

inventory excludes the pairs /s θ/, /z ð/, and/or /l r/. If *both* sounds of a given pair are produced with 0% accuracy as potential treatment targets (columns), extra credit will be assigned in the row labelled PEC. However, if one member of the given pair is a potential treatment target, but not the other, extra credit will not be assigned. For example, if a child excludes both /l r/ from the inventory, then one extra credit point for phonetic complexity would be assigned to each sound, /l/ and /r/, in the row labelled PEC. On the other hand, if a child excludes /l/, but produces /r/ accurately, then neither /l/ nor /r/ would receive extra credit for phonetic complexity. This will be illustrated further in the context of the clinical case, presented below.

Finally, at the very bottom of the matrix, is another place to total all points, with space to identify an optimal treatment target and probe sounds that are based on the generalization predicted from the collective evidence associated with error patterns, implicational laws, developmental norms, and stimulability.

Clinical application

In this section, the matrix of generalization is applied to a clinical case drawn from the dissertation of Miccio (1995). That work evaluated the acoustic and perceptual characteristics of fricatives produced by children with typical and disordered phonological systems. The focus was not on the selection of target sounds for treatment, nor on predictions of generalization that might derive from the efficacy literature. Nonetheless, Miccio (1995) reported relevant descriptive phonological data that are extended herein to demonstrate how the matrix of generalization may be used to inform treatment target selection and identification of relevant probe sounds.

The data come from Child T2, a girl, aged 3 years, 10 months. Miccio (1995: 34) reported that the child's hearing and oral-motor structure and function were within expected limits. Child T2 also had a standard score of 95 on the *Peabody Picture Vocabulary Test* (Dunn and Dunn, 1981), and her performance on the *Goldman-Fristoe Test of Articulation* (Goldman and Fristoe, 1986) was < 1% relative to normative data from age- and gender-matched peers. Of particular interest was Child T2's reduced consonantal inventory. Miccio (1995: 53) reported that 14 target English sounds were excluded from Child T2's inventory, as established from phonological analyses of production probe data obtained upon enrolment in the study. The sounds excluded are shown in Table II, with these being produced with 0% baseline accuracy. Also in Table II are the sounds that Miccio identified as being stimulable. These data will now be evaluated relative to the matrix of generalization to illustrate evidence-based target sound selection.

The first step is to mark (circle or highlight) the sounds that will be considered as potential treatment targets. Following efficacy data, these are the sounds produced with 0% accuracy by a child. For Child T2, in particular, all of the sounds displayed in Table II are to be marked in the respective columns of the matrix. This is shown in Figure 2 using reverse shading (i.e. irrelevant information is shaded out to highlight the relevant properties for the reader).

The next step is to mark the sounds that will be evaluated for generalization. This information is to be entered in the rows of the matrix. The rows establish the potential set of sounds that will be probed for generalization with, and in the absence of, direct treatment. For Child T2, the sounds in Table II are highlighted again, but now in the respective rows of the matrix. This is depicted in Figure 2.

With these notations in place, the predictive power of the set of potential treatment targets will be evaluated by considering the intersecting columns and rows. We begin with /θ/

(column) as a possible treatment target, and ask whether treatment of /θ/ is predictive of generalization by examining the pertinent rows of the matrix. This is done by tracing down the /θ/ column and counting the bullet and diamond notations (in the non-shaded cells) for only those error sounds applicable to Child T2's phonology. Specifically, if /θ/ were to be treated, there is no predicted generalization to /ŋ/. Notice that, when column /θ/ intersects row /ŋ/, there is no corresponding bullet or diamond notation to denote a predictable co-occurrence involving these two segments. Continuing down the same column, if /θ/ were to be treated, there is predictable generalization to /k g/, as indicated by the bullet notations. Change in /k g/ is expected because of the lawful co-occurrence relationship between fricatives and stops (Table I). Continuing further down the same column, change is also expected in /θ/, as indicated by the diamond notation, because we are entertaining /θ/ as a potential treatment target. Continuing further still, there is no additional generalization that is expected to follow from treatment of /θ/ because there are no other instances of bullet or diamond notation in relevant intersecting cells pertinent to Child T2's phonology. Thus, '3' is entered into the corresponding SUM cell. This is the tally of the two bullets shown for /k g/ and the one diamond for /θ/.

The tallying process advances to the next column /ð/ of Figure 2. If /ð/ were selected as the potential treatment target, the prediction is that generalization would extend to /k g f θ ð s ʃ tʃ/. Notice that, when column /ð/ intersects each of the rows /k g f θ ð s ʃ tʃ/, there are bullet and diamond notations denoting predictable co-occurrence relationships defined by implicational universals. Hence, /k g f θ ð s ʃ tʃ/ are predicted to generalize, with nine notations in all. Therefore, '9' is entered in the corresponding SUM cell of Figure 2.

As yet one more example, if /s/ were selected as a potential treatment target, generalization is expected for /k g s/, following from two bullets and one diamond notation in the relevant intersecting column and rows. In Figure 2, '3' is reported in the SUM cell that corresponds to potential treatment target /s/.

This process of tally, then sum continues on in the same way for each of the remaining sounds that are being considered as potential treatment targets. The resulting sums are shown in Figure 2.

At this point in application of the matrix, the efficacy evidence associated with the nature of error patterns and implicational laws have been weighed relative to the clinical case of Child T2. The next step is to evaluate the 'extra credit' factors of developmental norms and stimulability. Following from Table II, Child T2 produced the late-8 sounds /θ ð s z ʃ l r/ with 0% accuracy. These have been pre-tagged for extra credit on the matrix because of their apparent impact on system-wide generalization; this is shown in the row DEC of Figure 2. Child T2 was reportedly stimutable for /f v dʒ/. These sounds will not receive extra credit for stimulability, keeping in mind that the efficacy evidence supports *non-stimulable* sounds as promoting greater generalization. Consequently, all potential treatment targets, except /f v dʒ/, are assigned one extra credit point in the row marked SEC, as shown in Figure 2.

Additional extra credit goes to each of the pairs of sounds /s θ/, /z ð/, and /r l/. Recall that any one of these pairs predicts generalization that cross-cuts the inventory. Because Child T2 excludes both members of the /s θ/ pair, these potential treatment targets each receive one extra credit point, entered in the row PEC. Likewise, because both /z ð/, and also /r l/ were excluded from Child T2's inventory, these pairs too each receive one extra credit point, as in Figure 2.

The final step in application of the matrix involves totalling the points received by each sound in the pool of potential treatment targets. That sound with the greatest number of

points is identified as the favoured candidate for treatment given the combined efficacy results associated with error patterns, implicational laws, developmental norms, and stimulability. In the case of Child T2, it can be seen that /dʒ/, with 16 points, emerges as the treatment target that has the potential to maximally induce generalization. Thus, /dʒ/ is listed as the treated sound on the matrix of generalization.

The matrix provides further guidance about the specific sounds that are predicted to change following treatment. These should be monitored and probed in the course of intervention. In the case of Child T2, assuming treatment of /dʒ/, generalization gains are expected, specifically in /k g f v θ ð s z ʃ tʃ dʒ/. The latter were determined by consulting column /dʒ/ as the treatment target, and extracting the specific sounds predicted to change, as marked by the bullet and diamond notations. Thus, the matrix utilizes evidence-based practice in two ways: in selection of treatment targets and in the development of appropriate probes to document phonological generalization.

Before leaving the case of Child T2, it is relevant to take note of other viable treatment targets (and corresponding probe sounds) identified from the matrix. In Figure 2, it can be seen that /ð z/ were assigned 12 points and /tʃ/ 11 points. These targets too would be anticipated to result in sizeable expansion of Child T2's inventory, and are viable alternatives to treatment of /dʒ/. The point is that the matrix is designed to guide, not dictate, treatment decisions that follow from evidence-based practice. Even within an evidence-based approach, a complex set of variables associated with each individual child's profile will necessarily contribute to the clinical decision-making process. The aim is to use the evidence to support and inform the selection of treatment targets to promote system-wide phonological generalization, while recognizing the uniqueness of each child.

Applied extensions

The matrix of generalization is intended to capture a core sub-set of factors that may be considered in target sound selection. The matrix is limited, however, by the available evidence that is associated with each of the factors. For example, it is not yet known whether there is a hierarchical relationship between error patterns, implicational universals, developmental norms, or stimulability. As applied in the matrix, these were given equal weight in identification of a potential treatment target. With continued experimental clinical research, it is possible that one factor may emerge as more important to treatment efficacy than another.

As another example, the matrix identifies potential treatment targets based on summing the evidence. This is not meant to also imply that generalization accuracy will be additive because this has not yet been established in the efficacy literature. For example, in Figure 2, /ð/ received a total score of 12, and /θ/ 6. It cannot be said that treatment of /ð/ will result in twice greater generalization than treatment of /θ/; rather, treatment of /ð/ has the potential to affect change in a broader range of sounds than /θ/. This too is an issue that remains for future research, with possible implications for refinement of the matrix.

As designed, the matrix of generalization considers a finite sub-set of the factors that have been shown to impact treatment efficacy. It is possible that alternate matrices may be crafted, which follow from complementary variables that bear on children's learning in phonological treatment. For example, matrices that appeal to lexical factors in selection of treated words (Leonard and Ritterman, 1971; Morrisette and Gierut, 2002; Storkel and Morrisette, 2002; Storkel, 2004; Beckman, Munson, and Edwards, 2007) or to syllabic factors in selection of treated clusters (Gierut, 1999; Gierut and Champion, 2001; Morrisette, Farris, and Gierut, 2006) may be developed as other predictive options. Thus, the matrix of generalization may serve two purposes: as an immediate clinical tool that accords with

evidence-based practice, and as a template for potential use in creating complementary clinical tools that are also based on treatment efficacy.

In closing, this paper demonstrated how a sub-set of results from experimental treatment research on children with phonological disorders might be applied to the selection of treatment targets. The generalization matrix adds to a growing core of translations from research to practice that may aid in clinicians' access to relevant efficacy evidence and implementation of that evidence in direct clinical practice.

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		POTENTIAL TREATMENT TARGETS																							
		Late-8								Mid-8								Early-8							
		θ	ð	s	z	ʃ	ʒ	l	r	ŋ	t	k	g	f	v	tʃ	dʒ	m	n	p	b	d	w	j	h
m							•	•									♦								
n							•	•										♦							
ŋ							•	•	♦																
p	•	••	•	••	•	••						•	•	••	•	••			♦	•	•				
b	•	•	•	•	•	•							•	•	•	•				♦					
t	•	••	•	••	•	••			♦			•	•	••	•	••					•	•			
d	•	•	•	•	•	•							•	•	•	•						♦			
k	•	••	•	••	•	••					♦	•	•	••	•	••					•	•			
g	•	•	•	•	•	•						♦	•	•	•	•									
f		•		•		•						•	♦	•	•	••					•	•			
v														♦	•	•									
θ	♦	•		•		•						•		•	•	••					•	•			
ð		♦														•	•								
s		•	♦	•		•						•		•	•	••					•	•			
z				♦											•	•									
ʃ		•		•	♦	•						•		•	•	••					•	•			
ʒ							♦									•	•								
tʃ		•		•		•						•		•	♦	•					•	•			
dʒ																	♦								
l							♦																		
r								♦																	
w																							♦		
j																								♦	
h																									♦
SUM																									
DEC	1	1	1	1	1	1	1	1																	
SEC																									
PEC																									
TOTAL																									

Treatment Target:	Probe Sounds:
-------------------	---------------

Figure 1.
Matrix of generalization.

		POTENTIAL TREATMENT TARGETS																								
		Late-8								Mid-8								Early-8								
		θ	ð	s	z	ʃ	ʒ	l	r	ŋ	t	k	g	f	v	tʃ	dʒ	m	n	p	b	d	w	j	h	
m																		♦								
n																			♦							
ŋ																			♦							
p																										
b																										
t																										
d																										
k																										
g																										
f																										
v																										
θ																										
ð																										
s																										
z																										
ʃ																										
ʒ																										
tʃ																										
dʒ																										
l																										
r																										
w																										
j																										
h																										
SUM	3	9	3	9	3		2	2	1		1	7	3	9	10	16										
DEC	1	1	1	1	1	1	1	1																		
SEC	1	1	1	1	1		1	1	1		1	1	0	0	1	0										
PEC	1	1	1	1			1	1																		
TOTAL	6	12	6	12	5		5	5	2		2	8	3	9	11	16										

Treatment Target: dʒ	Probe Sounds: k g f v θ ð s z ʃ tʃ dʒ
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Figure 2.
Matrix of generalization for child T2.

Table I

Implicational universals incorporated in the generalization matrix.

Predicting property X	Property Y predicted to change
Fricatives	Stops
Affricates	Fricatives
Voiced obstruents	Voiceless obstruents
Liquids	Nasals
Pairs /s θ/, /z ð/, /l r/	All phonetic manner categories

Table II

Target sounds excluded from the inventory of Child T2, as reported by Miccio (1995: 53).

				ŋ
				k g
<u>f</u> v	θ ð	s z	ʃ	
			tʃ dʒ	
		l	r	

Sounds underlined were stimuable.