

## Clinical Forum

# Case Study: Optimality Theory and the Assessment and Treatment of Phonological Disorders

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Optimality theory is a formal linguistic framework for describing grammatical systems that was first developed in the early 1990s (McCarthy & Prince, 1994, 1995; Prince & Smolensky, 1993). The theory has been extremely influential in the field of phonology in particular, and has been appealed to in order to account for acquisition facts (Barlow, 2001b; Barlow & Dinnsen, 1998; Bernhardt & Stemberger,

**ABSTRACT:** Recently, the development of the constraint-based framework of optimality theory has been adopted and applied to the assessment and treatment of children with phonological disorders. This paper provides a demonstration of the application of optimality theory to the assessment and treatment of a single child with a phonological disorder. First, a tutorial of the theory is provided. Then, several prototypical error patterns evident in the child's productions are analyzed within the framework. These errors are accounted for by assuming that constraints against marked structure are ranked over constraints that require faithfulness to input forms within the child's grammar. Following that, a demonstration of how optimality theory accounts for different types of variation in the child's productions is provided. These different types of variation are revealing of the true nature of certain error patterns, particularly an apparent pattern of cluster reduction. Finally, the results of the analysis lead to suggestions for treatment that focus on the demotion of markedness constraints below faithfulness constraints.

**KEY WORDS:** optimality theory, constraint, phonological disorders, assessment, treatment

1998; Demuth, 1995; Dinnsen & Barlow, 1998; Dinnsen, McGarrity, O'Connor, & Swanson, 2000; Gnanadesikan, 1996; Goad, 1998; Ohala, 1996; Ota, 1998; Pater, 1997; Pater & Paradis, 1996; Smolensky, 1996a, 1996b).<sup>1</sup>

This paper demonstrates the application of optimality theory to the assessment and treatment of phonological disorders. First, an overview of the concepts and terminology of the theory is provided. Then, the formalism of the theory is illustrated through an account of commonly occurring error patterns as produced by an individual child. Then, the theory is extended to account for variation that occurs in that same child's productions. Finally, suggestions for treatment based on the analysis are provided.

### BASICS OF OPTIMALITY THEORY: TERMINOLOGY AND FORMALISM

The goal of a linguistic theory is to explain the grammatical systems of language. This includes, among other things, accounting for the difference between *mental representations* (the underlying phonemic structure of a given word) and *surface representations* (the phonetic forms that are actually spoken). In the majority of linguistic frameworks to date, the difference between mental and surface representations is attributed to the occurrence of rules or processes.

<sup>1</sup> For a detailed description and evaluation of this version of optimality theory as it applies to developing systems, see Barlow and Gierut (1999). For a more extensive description of developing systems within a considerably different constraint-based framework, see Bernhardt and Stemberger (1998).

Optimality theory is different from the majority of linguistic frameworks in that it does not appeal to rules or processes to explain such patterns in grammar; instead, it appeals to *constraints*, which are assumed to be universal across all languages and all speakers of all languages. Specifically, in optimality theory grammars, there is a specified relationship between input and output representations, and these are similar to the mapping between mental and surface representations in rule- or process-based theories. However, in optimality theory, the input and output are mediated by two functions, called GEN, or generator, and EVAL, or evaluator (Figure 1).

For any given input form such as /kæt/, which is the mental representation of the word *cat*, GEN generates an infinite number of possible phonetic output (or candidate) forms for that input. All of these output forms compete with one another, but the grammar chooses only one output as the winning, or optimal, phonetic form. Some of the competing forms are similar or identical to the input (e.g., [kæt]), whereas some are very different (e.g., [bab] or [mu]). EVAL evaluates all of these possible outputs in parallel and chooses the output form that is most optimal for the grammar as the winning output form. The optimality of output forms is evaluated through ranked constraints in the grammar. These constraints and their relative rankings restrict the structure of possible output forms.

### Nature of Constraints

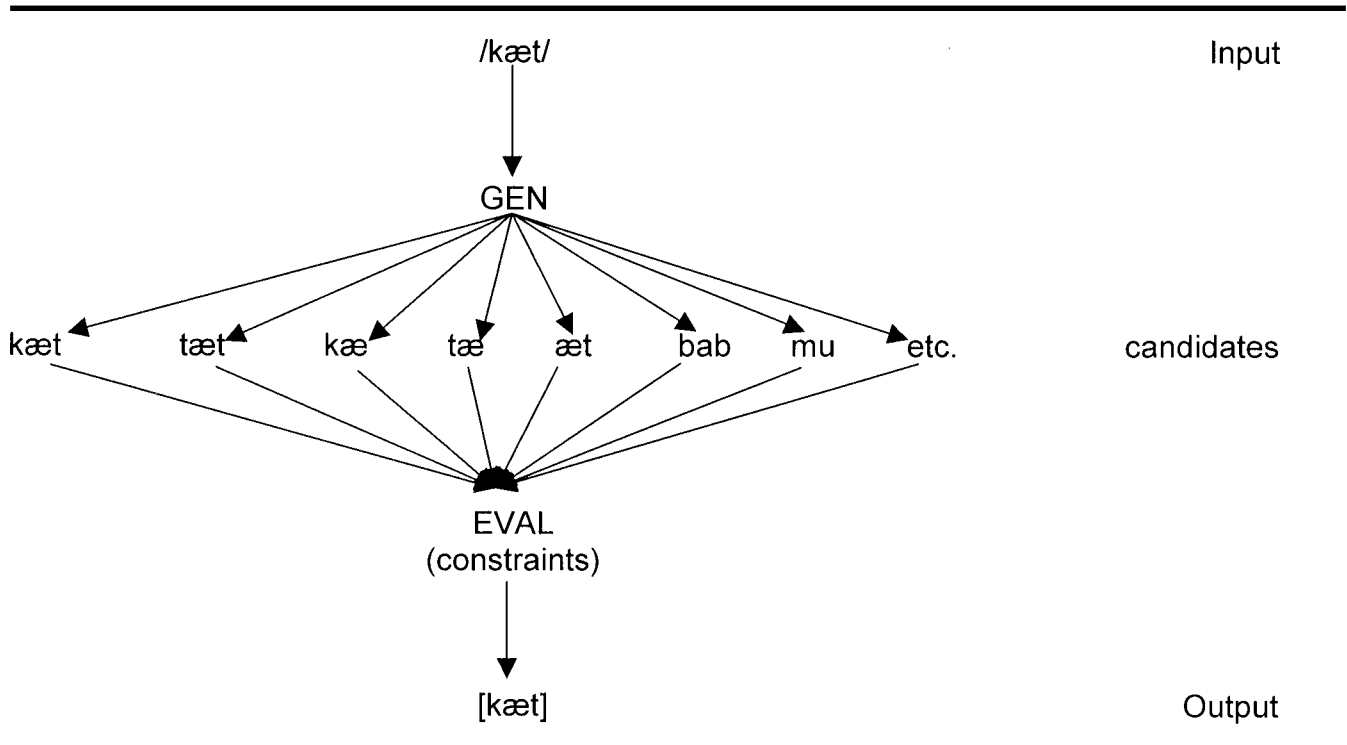
As stated previously, in optimality theory, constraints are universal, which means that they are present in all languages

and all grammars, including the grammars of developing systems. The way that grammars differ from one another is in their relative ranking of these constraints. In other words, all grammars have the same constraints, but each constraint is ranked in a grammar-specific order. The difference in rankings means that some constraints have a more important role in a given grammar than other constraints. Higher ranked constraints are more important in the grammar; thus, the output form that violates the fewest highest ranked constraints is chosen by EVAL as optimal.

There are two types of constraints: faithfulness constraints and markedness constraints.

- *Faithfulness constraints* require input and output forms to be identical to one another. If segments are deleted, inserted, or changed in terms of their featural makeup, faithfulness constraints are violated. For example, if a child produces the word *sleep* as [sip], a faithfulness constraint called MAX (“no deletion”; McCarthy & Prince, 1995) is violated because the /l/ is omitted. Similarly, if *sleep* is pronounced as [swip], a faithfulness constraint called IDENT-FEATURE (“don’t change manner features”; McCarthy & Prince, 1995) is violated because the /l/ changed to a [w]. Notice that both of the examples of errors on *sleep* result in homonymy with *seep* and *sweep*. Increased homonymy in a language leads to increased ambiguity. Therefore, faithfulness constraints are important for maintaining contrasts between the surface forms of words in order to avoid homonymy.
- *Markedness constraints* require outputs to be unmarked or simplified in structure. Properties of sound

Figure 1. Schematic of optimality theory (adapted from Archangeli, 1997).



systems that are marked are determined by perceptual and phonetic characteristics, as well as by the frequency and distribution of sound properties within and across languages. Those structures that are more difficult to perceive or produce, or that have limited occurrence cross-linguistically, are marked. Specifically, fricatives, affricates, liquids, and consonant clusters are examples of marked properties of language, whereas vowels, glides, nasals, and stops are examples of unmarked properties of language. Many languages lack marked sounds or sequences; in addition, marked structures typically are acquired relatively late by children and pose difficulty for second-language learners (Blevins, 1995; Eckman, 1984, 1985; Eckman, Moravcsik, & Wirth, 1983; Greenberg, 1978; Hawkins, 1987; Maddieson, 1984; Smit, Hand, Freilinger, Bernthal, & Bird, 1990). The occurrence of marked structures in output forms results in a violation of markedness constraints. Thus, the word *sweep* pronounced as [swip] violates a markedness constraint called \*COMPLEX (“no clusters”; McCarthy & Prince, 1995) due to the marked cluster [sw-].

Because of the conflicting nature of the two types of universal constraints, there is an antagonistic relationship between faithfulness and markedness constraints. If a grammar allows *sweep* to surface as relatively unmarked [sip], violation of \*COMPLEX is avoided; however, this entails a violation of the faithfulness constraint MAX, because /w/ is deleted. On the other hand, if a different grammar forces *sweep* to surface as [swip], violation of the faithfulness constraint MAX is avoided (because no segments are deleted); however, the markedness constraint \*COMPLEX is violated because of the marked [sw-] cluster. The difference between the two grammars lies in the ranking of constraints. In the former grammar, satisfaction of \*COMPLEX is more important than satisfaction of MAX, meaning that \*COMPLEX outranks MAX. In the latter grammar, MAX is more important than \*COMPLEX; thus, MAX outranks \*COMPLEX.

The conflict between faithfulness and markedness leads to *constraint violability*. Specifically, every output violates some constraint. In any grammar, for any input representation, certain faithfulness constraints are violated while satisfying certain markedness constraints, and certain markedness constraints are violated while satisfying certain faithfulness constraints in determining the optimal output forms. Violations of lower ranked constraints typically have no effect on the selection of output forms, whereas violations of higher ranked constraints always do. In phonological analysis, the goal is to determine what the specific ranking is for a given sound system, based on the production facts. In the case of developing systems, which is the focus of this paper, it is necessary to determine what specific ranking of constraints yields both the child’s correct and erred productions based on a reliable sample of speech.

In some cases, variability in possible output forms occurs, whereby the grammar allows either of two competing outputs to surface. Such a grammar might, for example, allow *sweep* to surface as both [swip] and [sip]. In such a

case, constraints may be organized into strata, such that they are ranked equally rather than hierarchically (known as *stratified domination hierarchies*; Tesar & Smolensky, 2000). Thus, two conflicting constraints that are ranked equally within a stratum allow for more than one competing candidate to be chosen as optimal. In the case of a grammar that allows *sweep* to surface as both [swip] and [sip], \*COMPLEX and MAX must be ranked equally.<sup>2</sup>

## Constraints Defined

The constraints that are relevant to this paper are shown in Table 1. For each constraint, a definition and examples of forms that violate or satisfy the constraint are provided. Each constraint considered has been motivated elsewhere in the optimality theory literature based on independent linguistic evidence from fully developed languages, historical sound change, dialect differences, and/or phonological development.

The markedness constraint \*COMPLEX (McCarthy & Prince, 1995) was discussed in the previous section. Cluster reduction (*sweep* → [sip]) occurs in order to avoid a violation of \*COMPLEX. Clusters are considered marked because of their limited occurrence in languages of the world (Blevins, 1995), and because children and second-language learners often produce them in error (Eckman, 1984; Eckman et al., 1983; Ingram, 1989a; Locke, 1983).

\*CODA (McCarthy & Prince, 1995) is a markedness constraint against syllable-final consonants (codas), and therefore prohibits codas from outputs. In other words, coda consonants are marked linguistically, and this is reflected in the fact that many languages disallow final consonants (Blevins, 1995). Also, many children delete final consonants in the acquisition of languages that allow final consonants (Ingram, 1989a; Locke, 1983). When outputs include final consonants, \*CODA is violated. Deletion of final consonants (*cat* → [kæ]) occurs in order to avoid violation of \*CODA. Children who exhibit final consonant deletion have \*CODA ranked high in their grammars.

The markedness constraint \*FRICATIVES (“no fricatives”; Barlow, 1997; Barlow & Gierut, 1999) prohibits fricatives in outputs, whereas the constraint \*LIQUIDS (“no liquids”; Barlow, 1997; Barlow & Gierut, 1999) prohibits liquids. Both fricatives and liquids are considered marked, as evidenced by their relatively limited occurrence cross-linguistically and by the fact that children often produce them in error (Hawkins, 1987; Maddieson, 1984; Smit et al., 1990). When children produce fricatives as stops (*sun* → [tʌn]), violation of \*FRICATIVES is avoided; when they produce liquids as glides (*lake* → [wek]), violation of \*LIQUIDS is avoided. Thus, children who exhibit patterns of

<sup>2</sup> Alternatively, \*COMPLEX and MAX may be ranked along a continuous, rather than discrete, scale, thereby allowing for some overlap between the two ranked constraints (Continuous Ranking Scale; Boersma, 1998). This overlap results in variation in productions whereby constraints that are lower on the scale sometimes take precedence over constraints that are higher on the scale. Violation of the higher ranked constraint occurs less often than violation of the lower ranked constraint. If \*COMPLEX is ranked higher than but is overlapping with MAX, “sweep” surfaces as [sip] the majority of the time; [swip] occurs sporadically.

**Table 1.** Markedness and faithfulness constraints, with examples of violations and nonviolations.

<i>Constraint</i>	<i>Definition</i>	<i>Violation</i>	<i>Nonviolation</i>
<b>Markedness</b>			
*COMPLEX	No clusters	<i>sweep</i> → [swip]	<i>sweep</i> → [sip]
*CODA	No final consonants (no codas)	<i>cat</i> → [kæt]	<i>cat</i> → [kæ]
*FRICATIVES	No fricatives	<i>sun</i> → [sʌn]	<i>sun</i> → [tʌn]
*LIQUIDS	No liquids	<i>lake</i> → [lek]	<i>lake</i> → [wek]
		<i>rain</i> → [ren]	<i>rain</i> → [wen]
*LIQUID-[l]	No liquid [l]	<i>lake</i> → [lek]	<i>lake</i> → [wek]
*LIQUID-[r]	No liquid [r]	<i>rain</i> → [ren]	<i>rain</i> → [wen]
<b>Faithfulness</b>			
MAX	No deletion	<i>cat</i> → [kæ]	<i>cat</i> → [kæt]
		<i>sweep</i> → [sip]	<i>sweep</i> → [swip]
DEP	No insertion	<i>sweep</i> → [səwip]	<i>sweep</i> → [swip]
IDENT-FEATURE	Don't change features	<i>lake</i> → [wek]	<i>lake</i> → [lek]
		<i>sun</i> → [tʌn]	<i>sun</i> → [sʌn]
IDENT-[CONS]	Don't change [consonantal]	<i>lake</i> → [wek]	<i>lake</i> → [lek]
IDENT-[CONT]	Don't change [continuant]	<i>sun</i> → [tʌn]	<i>sun</i> → [sʌn]

stopping or gliding have \*FRICATIVES or \*LIQUIDS (respectively) ranked high in their grammars.

The constraint \*LIQUIDS is exploded into a family of constraints, \*LIQUID-[l] and \*LIQUID-[r], reflecting the fact that some sound systems allow, for example, liquid [l] but not liquid [r]. For such grammars, \*LIQUID-[r] is ranked relatively high, whereas \*LIQUID-[l] is ranked relatively low. The opposite ranking is likewise possible, where \*LIQUID-[l] is ranked relatively high and \*LIQUID-[r] is ranked relatively low. Both constraints are ranked high in those grammars that disallow liquids altogether; both are ranked low in those grammars that allow both types of liquids, as with adult speakers of English.

Recall that faithfulness constraints require that input and output forms be identical. The constraint MAX, which prohibits deletion, was discussed previously. If any segment is deleted (*cat* → [kæ]), MAX is violated. In the same way, the constraint DEP (“no insertion”; McCarthy & Prince, 1995) prohibits the insertion or addition of segments. If any segment is added to the output form (*sweep* → [səwip]), this constraint is violated. IDENT-FEATURE (“don’t change features”; McCarthy & Prince, 1995) constraints require that input features be preserved in output forms. In other words, any place, voice, or manner feature that is present in the input also should be present in the output. If any segment is changed in terms of featural characteristics, IDENT-FEATURE is violated. Fronting of velars to alveolars (*cat* → [tæt]), gliding of liquids (*lake* → [wek]), stopping of fricatives (*sun* → [tʌn]), prevocalic voicing (*cat* → [gæt]), and final obstruent devoicing (*dog* → [dɔk]) all are featural changes that incur an IDENT-FEATURE violation. This constraint typically is appealed to in its exploded form in terms of the specific features that are relevant to change, such as [continuant] for the stopping of fricatives or [consonantal] for the gliding of liquids. In this paper, only IDENT-[continuant] (“don’t change [continuant]”) and IDENT-[consonantal] (“don’t change [consonantal]”) are considered; however, it is recognized that other IDENT-FEATURE constraints (e.g.,

pertaining to place and voice) exist in universal grammar, as based on independent evidence (McCarthy & Prince, 1995).

Now that the basics of optimality theory have been discussed, its application to developing systems may be considered. The next section introduces optimality theory formalism by accounting for common error patterns in a child’s productions.

## EXTENSION OF OPTIMALITY THEORY: ACCOUNTING FOR A CHILD’S ERRORS

As a valid theoretical framework, optimality theory must be able to account for the error patterns exhibited in developing systems, whether typical or disordered. As stated previously, two languages differ in terms of the ranking of the universal constraints. Thus, Spanish has a different constraint ranking than English. Similarly, children have different constraint rankings than the adults of their surrounding speech community. Furthermore, individual children may have different constraint rankings from one another, and this is apparent in the extensive variation that occurs in phonological acquisition. Regardless of the ranking of any particular sound system, the grammar must resolve the conflict between the need for all outputs to be unmarked and the need to be faithful to input forms.

Determining constraint rankings is demonstrated next with an appeal to the productions of a child with a phonological disorder: “John” (aged 3:9 [years:months]). Data are drawn from single-word responses on the Bankson-Bernthal Test of Phonology (Bankson & Bernthal, 1990). The entire data set and more specific details concerning John are provided in Barlow (2001a); however, a subset of the data is considered here.

Example (1) reveals that John’s productions are different from the adult forms in that they are simplified. This is consistent with the production patterns of children generally

(Ingram, 1989a, 1989b; Stoel-Gammon & Dunn, 1985). In other words, children's outputs are unmarked during the initial stages of development. Optimality theory accounts for this by ranking markedness constraints over faithfulness constraints in the child's system (Gnanadesikan, 1996; Smolensky, 1996a, 1996b). The adult system has the opposite ranking, with faithfulness constraints ranked above relevant markedness constraints. Therefore, it is assumed that John's grammar is distinct from the target English sound system in that constraints are ranked in a different order. Recall that the very same constraints that operate in adult languages (such as English) also operate in children's grammars; thus, the effects of the ranked constraints reflect properties of grammar in general, not just children's grammars, and certainly not just John's grammar.

(1) Examples of John's simplified productions

Error pattern	Examples
Final consonant deletion	<i>hat</i> [hæ], <i>sled</i> [le], <i>pig</i> [bɪ]
Stopping	<i>shoe</i> [tu], <i>van</i> [bæn], <i>fish</i> [bɪʔ]
Cluster reduction	<i>sled</i> [le], <i>flag</i> [wæʔ], <i>butterfly</i> [bʌwɪ]
Gliding	<i>rain</i> [wen], <i>flag</i> [wæʔ], <i>radio</i> [weo]
Prevocalic voicing	<i>cow</i> [gəu], <i>pig</i> [bɪ], <i>cake</i> [geʔ]
Glottal replacement	<i>fish</i> [bɪʔ], <i>flag</i> [wæʔ], <i>bus</i> [bʌʔ]
Unstressed syllable deletion	<i>radio</i> [weo], <i>butterfly</i> [bʌwɪ]
Vocalization	<i>hammer</i> [hæmʊ], <i>fire</i> [baɪ]

Note that many of the productions in (1) show more than one error pattern. For example, *sled* [le] is an example of both cluster reduction and final consonant deletion. This production reflects the effects of more than one high-ranking markedness constraint that require outputs to differ from inputs in several respects. Optimality theory is capable of accounting for all such error patterns shown in (1); however, for space considerations, only a subset of these errors is considered in this paper. For now, only straightforward examples are considered for the purpose of showing how optimality theory accounts for common error patterns in children's speech. The analyses are simplified here, but are considered more in depth in the following section, where variability is discussed.

### Final Consonant Deletion

As shown in (1), final consonant deletion occurs in John's productions, such as with *hat* as [hæ]. This pattern reflects the ranking of the markedness constraint \*CODA ("no final consonants") over the faithfulness constraint MAX ("no deletion"). The conflict between the two constraints and their violability by different output forms is shown formally in a constraint tableau. Figure 2 shows a simplified sample tableau demonstrating how optimality theory accounts for the pattern of final consonant deletion.

Figure 2 illustrates the conflict between \*CODA and MAX. In the grammars of adult speakers of English, \*CODA is ranked relatively lower than MAX, meaning that final consonants are allowed to occur by the grammar; hence, the occurrence of the words *cat*, *dog*, and *bathtub*. However, a ranking such as that in the tableau in Figure 2

Figure 2. Final consonant deletion: *hat* /hæt/ → [hæ].

	/hæt/ <i>hat</i>	*CODA	MAX
a.	[hæt]	*!	
b.	[hæ]		*

**Note.** ☞ = optimal output; \* = constraint violation; \*! = fatal violation; | or , = equal ranking; | or >> = crucial ranking.

prevents final consonants from occurring, as \*CODA is ranked higher than MAX.

Specifically, in the tableau in Figure 2, the constraints are ranked across the top, from most important (on the left) to least important (on the right). The markedness constraint \*CODA is most important and therefore is ranked highest. In this case, \*CODA outranks the faithfulness constraint MAX. The ranking of constraints is indicated in (2), where the two constraints are separated by double right-angled brackets (">>").

(2) Final consonant deletion

\*CODA >> MAX

The input representation /hæt/ and its orthographic representation *hat* are shown in the upper left cell of the tableau. Sample output candidates (a) and (b) are shown along the left side. Only two candidates are shown: the faithful marked candidate (a) [hæt] and the unfaithful unmarked candidate (b) [hæ], where the final [t] is deleted. Recall that an infinite number of outputs is generated by GEN; however, the two most relevant candidates are considered here.

Candidate (a) is the faithful candidate because it is identical to the input. All segments in the input also are present in this output form: The input has not been altered in any way. This means that the faithfulness constraint MAX is satisfied by candidate (a). The cell under the MAX column for candidate (a) is left blank to indicate satisfaction of the MAX constraint. On the other hand, candidate (a) includes a final consonant [t], which is a violation of the higher ranked markedness constraint \*CODA. The violation of that constraint is indicated by an asterisk ("\*") in the corresponding cell. Candidate (b) does not violate \*CODA because it has no final consonant: /t/ is deleted. Therefore, the cell under the \*CODA column for candidate (b) is left blank. Because /t/ is deleted, candidate (b) is in violation of the faithfulness constraint MAX. An asterisk indicates that violation in the corresponding cell.

Thus, both candidates violate one of the constraints; however, one violation is more serious than the other. Violation of higher ranked constraints is always worse than violation of lower ranked constraints. Therefore, candidate (a)'s violation of higher ranked \*CODA is a fatal violation, and candidate (b)'s violation of lower ranked MAX is nonfatal (hence, the shading in the column for that constraint). The fatal violation is indicated with the exclamation point ("!") and eliminates the candidate from being chosen

as optimal by the grammar. Accordingly, candidate (b) is chosen by the grammar as the optimal candidate (the form that John actually produces), and this is shown by the manual indicator (“☞”) to the left of candidate (b). In John’s grammar, it appears that it is better to violate the faithfulness constraint MAX than it is to have a final consonant in the output. Thus, to account for final consonant deletion, \*CODA must outrank MAX. (This error pattern will be reconsidered in later sections when variation is addressed.)

## Stopping

Now consider John’s stopping error pattern, where *shoe* surfaces as [tu]. The constraints relevant here are \*FRICATIVES (“no fricatives”) and IDENT-[continuant] (“don’t change [continuant]”).<sup>3</sup> For stopping, the markedness constraint against fricatives outranks the constraint that requires faithfulness to the [continuant] feature, as shown in (3). Of course, English has the opposite ranking because fricatives occur in the productions of adult speakers.

### (3) Stopping

\*FRICATIVES >> IDENT-[continuant]

This ranking is shown in the tableau in Figure 3, with the highest ranked constraint on the left. For the word *shoe*, two possible output candidates are shown on the left side of the tableau: the faithful marked candidate (a) [ʃu], and the unfaithful unmarked candidate (b) [tu]. Because \*FRICATIVES outranks IDENT-[continuant], it is a more serious violation of John’s grammar to have a fricative in the output. Therefore, candidate (a) incurs a fatal violation of \*FRICATIVES. Candidate (b), the less faithful candidate, violates IDENT-[continuant], because the output form includes a stop rather than a fricative. This is a nonfatal violation, making attested candidate (b) the winning output form. Thus, to account for John’s stopping pattern, \*FRICATIVES is ranked above IDENT-[continuant].

## Cluster Reduction

Cluster reduction also occurs in John’s data. Children’s productions often involve reducing clusters to singletons, as with *sled* produced as [lɛ]. \*COMPLEX (“no clusters”) typically is responsible for cluster reduction patterns, and it

Figure 3. Stopping: *shoe* /ʃu/ → [tu].

	/ʃu/ <i>shoe</i>	*FRICATIVES	IDENT-[continuant]
a.	[ʃu]	*!	
b.	☞ [tu]		*

<sup>3</sup> Note that MAX is not relevant here because the fricative /ʃ/ in the input has simply changed in terms of the [continuant] feature; the segment itself has not been deleted. MAX prohibits the deletion of segments only. Similarly, DEP is not relevant because no segments are inserted.

therefore must be ranked above MAX (“no deletion”), as shown in (4).

### (4) Cluster reduction

\*COMPLEX >> MAX

Consider the tableau in Figure 4. When \*COMPLEX is a higher ranked constraint, it is a more serious violation of the grammar to have a cluster in the output. Therefore, candidate (a) [slɛ] incurs a fatal violation for that constraint. Candidate (b) [lɛ] satisfies \*COMPLEX because there is no cluster in that output form; however, candidate (b) violates MAX because /s/ is deleted. Again, this is a nonfatal violation, and the attested candidate (b) is the winning output. Therefore, to account for cluster reduction, \*COMPLEX is ranked over MAX. (This error pattern and additional candidate forms will be reconsidered in later sections when variation is addressed.)

Notice that an alternative candidate [sɛ] is not considered in this example. Because \*FRICATIVES is assumed to be highly ranked in John’s grammar as a result of the observed stopping pattern (*shoe* → [tu]), [sɛ] would be ruled out by the grammar because of a fatal violation of that markedness constraint.

Notice also that John’s production of *sled* [lɛ] involves final consonant deletion because /d/ is omitted. As with the previous example of *hat* produced as [hæ], it is assumed that \*CODA is highly ranked and therefore responsible for the deleted /d/ in *sled*. Accordingly, for the tableau in Figure 4, the possible output forms were candidate (a) [slɛ], which maintains the [sl-] cluster, and candidate (b) [lɛ], which reduces the cluster to the singleton [l]. Both exclude the final consonant [d]. However, additional candidate output forms, such as [slɛd] and [lɛd], would be ruled out by the proposed grammar because of high ranking \*CODA. (This is reconsidered under an alternative analysis in later sections.)

## Gliding

John also exhibits a gliding pattern, evident in his productions of *rain* [wen] and *yellow* [jɛwɔʊ]. To account for John’s gliding pattern, it is assumed that \*LIQUIDS (“no liquids”) outranks IDENT-[consonantal] (“don’t change [consonantal]”),<sup>4</sup> as in (5) below. Accordingly, it is a worse violation of John’s grammar for a liquid such as [r] to

Figure 4. Cluster reduction: *sled* /slɛd/ → [lɛ].

	/slɛd/ <i>sled</i>	*COMPLEX	MAX
a.	[slɛ]	*!	
b.	☞ [lɛ]		*

<sup>4</sup> For all examples of gliding, it is assumed that a violation of IDENT-[consonantal] as opposed to IDENT-[coronal] (“don’t change coronals”) is incurred because the major class feature [consonantal] is changed. Gliding does involve a change in both [consonantal] and [coronal]; nevertheless, [consonantal] serves as the contrasting feature between glides and liquids.

surface in the output than it is to change the [consonantal] feature of a liquid in the input.

(5) Gliding

\*LIQUIDS >> IDENT-[consonantal]

This ranking is illustrated in the tableau in Figure 5. For the word *rain*, two possible output candidates are considered: the faithful marked candidate (a) [ren] and the unfaithful unmarked candidate (b) [wen]. As with previous examples, the unmarked candidate (b) is the output preferred by John's grammar due to the higher ranking markedness constraint \*LIQUIDS. Thus, to account for the gliding pattern, \*LIQUIDS must outrank IDENT-[consonantal]. (This error pattern will be reconsidered in more detail in the next section.)


To summarize, common error patterns, such as final consonant deletion, stopping, cluster reduction, and gliding, as exhibited in John's data, can be explained within optimality theory by assuming that markedness constraints outrank faithfulness constraints. These proposed rankings explain why children's productions typically are unmarked in structure. However, some of these error patterns exhibited by John actually occur optionally or variably, which is consistent with production patterns of most children (Rice, 1996; Rice & Avery, 1995; Stoel-Gammon & Dunn, 1985).

To take an example, notice that /n/ occurs in coda position in John's production of *rain* as [wen]; the pattern of final consonant deletion did not apply in this production. Likewise, a brief glance at the entire data set provided in Barlow (2001a) reveals that some clusters actually do occur in John's productions. Finally, the liquid [l] is allowed to occur in some of John's productions, as in *sled* [le], which was not affected by the gliding pattern. A more in-depth analysis of these error patterns is considered in the following section, where it is shown that the original rankings proposed do not adequately account for John's productions overall.

## EXTENSION OF OPTIMALITY THEORY: ACCOUNTING FOR VARIATION IN JOHN'S PRODUCTION PATTERNS

As a valid theoretical framework, optimality theory also must be able to account for the variation that is exhibited in John's productions, as well as the variation that is exhibited within and across other sound systems, whether developing or fully developed. Optimality theory accounts for variation quite eloquently. First, intraword variation is

Figure 5. Gliding: *rain* /ren/ → [wen].

	/ren/ <i>rain</i>	*LIQUIDS	IDENT-[consonantal]
a.	[ren]	*!	
b.	 [wen]		*

attributed to the equal ranking of constraints within a stratum in the grammar, as mentioned previously (Tesar & Smolensky, 2000). Second, interword variation is attributed to the interaction between ranked constraints. Each type of variation is considered presently.

John shows variation in his use of error patterns, as shown in (6). Additional variation exists in his productions; however, for now, the variation that occurs with final consonant deletion, gliding, and cluster reduction is considered. The stopping pattern, which is not variable, also is relevant to this account.<sup>5</sup>

(6) Examples of John's variable error patterns

Error pattern	Occurs	Does not occur
Final consonant deletion	<i>hat</i> [hæ], <i>lion</i> [laɪə]	<i>gate</i> [get], <i>wagon</i> [wæɡən]
Gliding	<i>flag</i> [wæʔ], <i>yellow</i> [jɛwou]	<i>lamp</i> [læʔ], <i>lion</i> [laɪə]
Cluster reduction	<i>sled</i> [le], <i>flag</i> [wæʔ]	<i>clown</i> [kwaʊn], <i>crab</i> [kwæ]

## Intraword Variation: Equal Ranking of Constraints

Intraword variation occurs when, within a given grammar, the surface form for a word may vary. Although the data set from John is somewhat limited in that there is for the most part only one opportunity for each word to occur, the available data do hint of the possibility that individual words might be pronounced differently if they are sampled more than once. Examples of such variation in terms of the error patterns of final consonant deletion and gliding are considered next.

**Final consonant deletion.** The final consonant deletion pattern is notably variable in John's productions. Notice that John omits [t] in the word *hat*, but retains it in *gate* [get]. A similar comparison can be made with *carrot* [ɡeə], where [t] is omitted, as opposed to *elephant* [ɛbət], where [t] occurs. Variation also occurs with final [n]: *Lion* surfaces as [laɪə], whereas *gun* surfaces as [dʌn]. Whether or not a consonant surfaces word-finally does not seem to be unique to particular words because even the same word can surface variably in John's speech. The word *this* was targeted twice in the probe, and was produced first as [dɪ] and then as [dɪs]. These productions suggest that final consonant deletion is an optional pattern in his productions.

Recall that \*CODA was ranked above MAX in the tableau in Figure 2 in order to account for the final consonant deletion pattern in John's productions. However, with such a ranking, the grammar would never allow final consonants to occur. It is apparent that final consonants do sometimes occur. Consider John's production of the word *gate* (according to the original ranking proposed in (2)) in the

<sup>5</sup> Fricatives occur twice in John's speech sample: /s/ occurs in one of the two productions of *this* [dɪs], [dɪ]; /z/ occurs in an incorrect production of *goat* [goz]. No other fricatives occur. Thus, stopping is relatively consistent. To account for these two occurrences of fricatives within optimality theory, an appeal to Boersma's (1998) Continuous Ranking Scale is appropriate (see note 2).

tableau in Figure 6. With \*CODA ranked above MAX, the proposed grammar cannot allow for *gate* to surface as [get]—the attested form in John’s productions. Instead, the wrong candidate is chosen by the grammar, \*[ge], as indicated by the sad face symbol (“☹”). Thus, there is a ranking paradox.

To resolve the paradox, it is assumed that MAX and \*CODA are ranked equally. That is, John’s grammar treats outputs with codas and those without codas as equally optimal, just as English does (hence, the occurrence of pairs of words such as *bow* and *boat*). MAX and \*CODA ranked equally allows for the observed variation in John’s productions.

Figure 7 shows how the equal ranking of MAX and \*CODA results in nonfatal violations of the grammar by such outputs as candidates (a) [dɪs], and (b) [dɪ]. (Note that the equal ranking is indicated by a comma between the two constraints, as in (7), and the dashed line separating the two constraints in the tableau, as in Figure 7.) Thus, both candidates (a) and (b) are allowed by the grammar. Violation of one or the other of the two equally ranked constraints is treated equally by the grammar. Consider, on the other hand, a production with an inserted segment, such as in candidate (c) [dɪ.sə], where the addition of the vowel puts [s] into the beginning of the following syllable. Although candidate (c) has avoided violation of both MAX and \*CODA, it has incurred a violation of higher ranked DEP (“no insertion”) because of the epenthesized [ə].

(7) DEP >> \*CODA, MAX

This equal ranking of constraints does not allow target words that do not end in final consonants to surface variably. That is, the grammar prevents vowel-final words from surfacing variably with or without a final consonant. John’s data provide no evidence for such production patterns. This sort of epenthesis is prevented by the ranking in (7) because high-ranking DEP prohibits the insertion of

**Figure 6.** Incorrect ranking of MAX and \*CODA: *gate* /get/ → \*[ge], not [get].

/get/ <i>gate</i>	*CODA	MAX
a. [get]	*!	
b. ☹ [ge]		*

**Figure 7.** Variation with consonant-vowel-consonant (CVC) words: *this* /ðɪs/ → [dɪs] or [dɪ].

/ðɪs/ <i>this</i>	DEP	*CODA	MAX
a. ☞ [dɪs]		*	
b. ☞ [dɪ]			*
c. [dɪ.sə]	*!		

any consonant in a word such as *shoe*, as illustrated in Figure 8. John’s grammar allows *shoe* to occur as candidate (a) [tu] (with stopping occurring for target /ʃ/), but never as candidate (b) [tut]. This is due to candidate (b)’s violation of both \*CODA and DEP. Thus, in John’s grammar, the deletion of a final consonant ([dɪ]) or not ([dɪs]) is preferable to the addition of a segment to the output form ([dɪ.sə]). Ranking \*CODA and MAX equally below DEP has allowed for this sort of variation to occur.

**Gliding.** A similar situation arises with gliding. John exhibits a gliding pattern for /l/ in *flag* [wæʔ], but the [l] surfaces correctly in his production of *sled* [lɛ]. Similarly, *yellow* surfaces with a glide as in [jɛwəʊ]; however, *umbrella* surfaces with an [l], as in [əbɛlə]. This suggests that gliding of /l/ is an optional error pattern in John’s productions. However, gliding of /r/ is not optional in John’s grammar. In fact, [r] surfaces only once in John’s (incorrect) production of *zebra* as [dɪɪbwə]. In all other forms, target /r/ is affected by gliding, vocalization, or deletion patterns, depending on context. Thus, only gliding of /l/ is viewed as optional in John’s grammar.

Because gliding is optional for /l/, the ranking of \*LIQUIDS above IDENT-[consonantal] as illustrated in Figure 5 cannot account for the occurrence of a word such as *lion*, as shown in Figure 9, where output form \*[wɪɪə] is selected as the optimal form by the grammar. The differential behavior of the gliding pattern for /l/ and /r/ requires appealing to \*LIQUIDS in its exploded form: \*LIQUID-[r] and \*LIQUID-[l]. Because gliding of /r/ is not optional, it is assumed that \*LIQUID-[r] is ranked above IDENT-[consonantal] in John’s grammar; however, because gliding of /l/ is optional, it is assumed that \*LIQUID-[l] and IDENT-[consonantal] must be ranked equally. Ranking these two constraints below MAX, as in (8), allows gliding to occur optionally, but prevents deletion of segments.

(8) MAX >> \*LIQUID-[l], IDENT-[consonantal]

Consider the tableau for *yellow* in Figure 10. For target liquids, John’s grammar treats output forms with /l/ and



**Figure 8.** No variation with consonant-vowel (CV) words: *shoe* /ʃu/ → [tu], but not \*[tut].

/ʃu/ <i>shoe</i>	DEP	*CODA	MAX
a. ☞ [tu]			
b. [tut]	*!	*	

**Figure 9.** Incorrect ranking of \*LIQUIDS and IDENT-[consonantal]: *lion* /laɪən/ → \*[wɪɪə], not [laɪə].

/laɪən/ <i>lion</i>	*LIQUIDS	IDENT-[consonantal]
a. [laɪə]	*!	
b. ☹ [wɪɪə]		*

**Figure 10.** Variable gliding for target liquid forms: *yellow* /jɛlou/ → [jɛlou] or [jɛwou].

/jɛlou/ <i>yellow</i>	MAX	*LIQUID-[l]	IDENT-[consonantal]
a.  [jɛlou]		*	
b.  [jɛwou]			*
c. [jɛou]	*!		

those with glides as equally optimal and thus chooses both candidates (a) [jɛlou], and (b) [jɛwou], as equally optimal. This is in comparison to an alternative output form where /l/ is omitted in order to satisfy \*LIQUID-[l], as in candidate (c) [jɛou]. Because MAX is ranked highest, candidate (c) incurs a fatal violation, leaving candidates (a) and (b) as optimal.


Of course, target glides are not expected to surface as liquids, as there is no evidence of such productions in John's data. The ranking in (8) prevents that sort of variation from occurring, as shown in the tableau in Figure 11. In this case, the word *wagon* only surfaces with [w] as in candidate (a) [wægən], and never with a liquid such as [l] in candidate (b) \*[lægən], due to the violation of both \*LIQUID-[l] and IDENT-[consonantal] by candidate (b). Thus, in John's grammar, the occurrence of [l] or a glide in the output is preferable to deletion of the liquid. Ranking \*LIQUID-[l] and IDENT-[consonantal] equally below MAX allows for variation in the gliding pattern to occur in John's productions.

To summarize, the optionality of error patterns such as final consonant deletion and gliding of /l/, which allows for intraword variation, is attributed to the equal ranking of conflicting faithfulness and markedness constraints.

### Interword Variation: Constraint Interaction

John's productions also show a different kind of variation in terms of initial consonant cluster production. At first glance, it appears that cluster reduction is an optional pattern in John's grammar, as shown in the data in (6). However, on closer examination of John's productions, it is evident that fricative clusters are the only clusters that are reduced, whereas stop + liquid clusters are allowed to occur as clusters. Thus, *crab* [kwæ], *clown* [kwaʊn], and *train* [twen] surface with consonant clusters (along with gliding for /l/ and /r/ and optional final consonant deletion), whereas *flag* [wæʔ], *sled*, [lɛ], and *stove* [dod] are reduced (again, along with gliding and/or optional final consonant deletion).

**Figure 11.** No variation with target glide forms: *wagon* /wægən/ → [wægən], but not \*[lægən].

/wægən/ <i>wagon</i>	MAX	*LIQUID-[l]	IDENT-[consonantal]
a.  [wægən]			
b. [lægən]		*!	*

Because clusters do occur in John's productions, \*COMPLEX cannot be ranked over MAX, as originally suggested in (4) and Figure 4. Consider the tableau in Figure 12. It is clear that ranking \*COMPLEX over MAX prevents John's attested production of *clown* as candidate (a) [kwaʊn] from surfacing, thereby yielding the incorrect surface form, candidate (b) \*[kaʊn], as optimal.


This type of variation is different from that discussed in the previous section on intraword variation. Specifically, the variation observed with John's production of consonant clusters is not accounted for by ranking \*COMPLEX and MAX equally. In fact, \*COMPLEX is not relevant to explaining this variable cluster production pattern. Instead, the variation is attributed to \*FRICATIVES ranked above MAX, which is in turn ranked above \*COMPLEX, as shown in (9).

(9) \*FRICATIVES >> MAX >> \*COMPLEX


The fricative clusters are considered first in the tableau in Figure 13 for *sled*. Candidate (a) [slɛ] is ruled out by the grammar because the presence of [s] violates high-ranking \*FRICATIVES. Attested candidate (b) is chosen as optimal, despite its violation of lower ranked MAX. In fact, candidate (b) incurs two violations of MAX, whereas candidate (a) incorporates one violation of MAX. Regardless, candidate (b) is chosen as the winning form. Notice also that candidate (a)'s violation of \*COMPLEX was not the determining factor for the elimination of that output form; rather, the fatal violation of \*FRICATIVES was.<sup>6</sup>

The production of stop + liquid clusters is accounted for in the tableau in Figure 14 for *clown*. This account incorporates the same constraints ranked in the very same order shown in (9). The same kinds of candidates are considered as with Figure 13, with the difference being that these are target stop + liquid clusters, rather than fricative + liquid clusters. Because there are no fricatives in the candidate forms to violate \*FRICATIVES, the role of MAX becomes

**Figure 12.** Incorrect ranking of MAX and \*COMPLEX: *clown* /klaʊn/ → \*[kaʊn], not [kwaʊn].


/klaʊn/ <i>clown</i>	*COMPLEX	MAX
a. [kwaʊn]	*!	
b.  [kaʊn]		*

**Figure 13.** Reduction of fricative + liquid clusters: *sled* /slɛd/ → [lɛ].

/slɛd/ <i>sled</i>	*FRICATIVES	MAX	*COMPLEX
a. [slɛ]	*!	*	*
b.  [lɛ]		**	

<sup>6</sup> An additional candidate, [tɛ], is examined in Figure 15, when John's overall ranking is discussed.

**Figure 14.** No reduction of stop + liquid clusters: *clown* /klaʊn/ → [kwaʊn].

/klaʊn/ <i>clown</i>	*FRICATIVES	MAX	*COMPLEX
a.  [kwaʊn]			*
b. [kaʊn]		*!	

important for the selection of the optimal output. This time, the deletion of [w] in candidate (b) [kaʊn] results in a fatal violation of MAX, leaving candidate (a) [kwaʊn], which includes a cluster, as the optimal (attested) form.

Because \*COMPLEX was not relevant to accounting for the cluster reduction pattern for fricative + liquid clusters, and because clusters obviously are allowed by John's grammar, \*COMPLEX must be ranked low in John's grammar, as shown in Figures 13 and 14.

## SUMMARY OF OPTIMALITY THEORY ANALYSIS OF JOHN'S SYSTEM

Up to this point, John's error patterns have been evaluated on an individual basis, where only two or three constraints are ranked with respect to one another. From these individual rankings, a more general ranking of constraints can be determined, as shown in (10).

(10) Summary ranking of relevant constraints in John's grammar

\*FRICATIVES, DEP, \*LIQUID-[r] >> MAX, \*CODA, IDENT-[continuant] >> \*LIQUID-[l], IDENT-[consonantal], \*COMPLEX

Figure 3 illustrated how \*FRICATIVES must outrank IDENT-[continuant] in order to account for the stopping pattern. Figure 7 illustrated how DEP must be ranked above both MAX and \*CODA in order to account for the variable pattern of final consonant deletion. The observation that gliding was variable for /l/ but obligatory for /r/ indicated that \*LIQUID-[r] must be ranked above IDENT-[consonantal], and \*LIQUID-[l] must be ranked equally with IDENT-[consonantal]. This also is illustrated in Figure 10. Finally, a more detailed analysis of the cluster reduction patterns as shown in Figures 12, 13, and 14 suggested that \*COMPLEX is ranked low in John's grammar. Taken together, these accounts provide the overall ranking shown in (10).









The constraints in the highest stratum, \*FRICATIVES, DEP, and \*LIQUID-[r], are ranked equally with one another. Because they are highest ranked, violation of any of these constraints is disallowed in John's grammar. These constraints dominate the next highest stratum, including equally ranked MAX, \*CODA, and IDENT-[continuant], which in turn dominates the lowest stratum, including equally ranked \*LIQUID-[l], IDENT-[consonantal], and \*COMPLEX. Satisfaction of the lower ranked stratum is less critical in John's grammar; thus, these constraints may be violated in satisfaction of higher ranked constraints.

Consider the tableau in Figure 15, where the overall ranking illustrates how the words *clown* and *sled* surface in John's grammar. In this tableau, all nine constraints considered in this analysis are ranked across the top according to the ranking shown in (10). This time, many different output candidates are relevant to the analysis. Consider *clown* first, which is accounted for in the top half of the tableau. Within the highest stratum of constraints, candidate (h) [kəlaʊn] incurs a violation of DEP, due to the insertion of [ə]. This is a fatal violation, and candidate (h) is excluded as a possible output. The remaining candidates are tied in this stratum, and therefore the next highest stratum must evaluate them. Candidates (a), (b), (f), and (g) incur one violation each within this stratum; candidates (c), (d), and (e) incur two violations each. Because these latter candidates incur more violations within this stratum, they are excluded as possible outputs. This leaves candidates (a), (b), (f), and (g) to compete in the lowest stratum, where each incurs two violations. The four candidates remain tied at the lowest stratum. Thus, in the case of the target word *clown*, four candidates,—(a) [klaʊn], (b) [kwaʊn], (f) [klaʊ], and (g) [kwaʊ]—are chosen by the grammar as optimal. The bolded form, candidate (b) [kwaʊn], is the attested form; nevertheless, it is assumed that the other three forms are allowed to occur given the observed variability in John's production of final consonants (due to equal ranking of \*CODA and MAX), as well as the variability in the gliding of /l/ (due to equal ranking of \*LIQUID-[l] and IDENT-[consonantal]). It is assumed that a larger speech sample, with multiple opportunities for each word, might have allowed for this sort of variation to occur for *clown*. In addition, because of the limited number of attempted target clusters in the data set, there are no examples of target stop + liquid clusters produced with liquids. Gliding occurs in every example. However, the independent evidence for the optionality of the error pattern, as shown in Figure 10, suggests that such variation also occurs with these clusters.

Multiple optimal candidates also are chosen by the grammar for the target word *sled*, as shown in the lower half of the tableau in Figure 15. Candidates (a), (b), (c), (h), and (j) are excluded by the grammar due to fatal violations of constraints in the highest ranked stratum. At this point, candidates (d), (e), (f), (g), (i), and (k) remain tied, as none violates any constraints in that stratum. In the next stratum, candidates (d), (e), (f), (g), and (i) remain tied with one another, as each incurs two violations within that stratum. Candidate (k), on the other hand, is ruled out for incurring a third, fatal violation in that stratum. Finally, in the lowest stratum, all five candidates (d), (e), (f), (g), and (i) incur one violation each of \*LIQUID-[l] or IDENT-[consonantal]; however, candidate (i) also violates \*COMPLEX. Thus, candidate (i) incurs two violations within that stratum and the remaining four candidates incur only one. Accordingly, candidates (d) [led], (e) [wed], (f) [le], and (g) [we] are chosen by the grammar according to the proposed ranking in (10). Again, only one form, candidate (f) [le] (indicated in bold), is attested in John's productions; nevertheless, the other forms are predicted to occur, given a larger sample.

A summary ranking has been determined in order to account for several of John's error patterns. Of course, other aspects of John's sound system that have not been addressed

Figure 15. Summary ranking of constraints: *clown* and *sled*.

	*FRIC	DEP	*LIQ-[r]	MAX	*CODA	IDENT-[cont]	*LIQ-[l]	IDENT-[cons]	*COMP
<i>/klaʊn/ clown</i>									
a.  [klaʊn]					*		*		*
b.  [kwaʊn]					*			*	*
c. [kaʊn]				*	*!				
d. [laʊn]				*	*!		*		
e. [waʊn]				*	*!			*	
f.  [klaʊ]				*			*		*
g.  [kwaʊ]				*				*	*
h. [kəlaʊn]		*!			*		*		
<i>/sled/ sled</i>									
a. [sled]	*!				*		*		*
b. [swɛd]	*!				*			*	*
c. [sɛd]	*!			*	*				
d.  [led]				*	*		*		
e.  [wɛd]				*	*			*	
f.  [le]				**			*		
g.  [wɛ]				**				*	
h. [sələd]	*!	*			*		*		
i. [tled]					*	*	*		*!
j. [tələd]		*!			*	*	*		
k. [te]				**		*!			

in this paper also must be incorporated into the overall ranking. Specifically, errors related to voicing, glottal replacement, and unstressed syllable deletion, for example, require appeal to additional markedness and faithfulness constraints. However, this is beyond the scope of this paper.

An analysis of the errors and the different types of variation exhibited in John's productions within an optimality theory framework can lead to more focused goals for remediation, particularly in terms of the selection of treatment targets. The next section considers how optimality theory can guide treatment strategies for bringing John's grammar in line with the target system.

## RERANKING THE CONSTRAINTS: DETERMINING TREATMENT GOALS

A valid linguistic framework also must be able to account for change in grammars over time. In optimality

theory, it is assumed that grammatical change occurs through constraint reranking. Therefore, in order for typically developing children to gradually achieve production patterns similar to the adult system, their grammars must change so that constraints rerank, allowing for the demotion of markedness constraints below faithfulness constraints. How exactly children's grammars develop over time is still under debate within the optimality theory literature (e.g., Boersma, 1998; Boersma & Hayes, 2001; Hayes, 1999; Tesar & Smolensky, 2000). Regardless, it is generally assumed that, in acquisition, markedness constraints are demoted in response to positive evidence from the surrounding speech community that two constraints should be in a specific ranking relationship.

In the case of children with phonological disorders, it is necessary for a speech-language pathologist to provide this positive evidence more directly; however, the ultimate goal is the same—to rerank constraints. Thus, the clinician's job is to select targets that induce the demotion of high-ranking

markedness constraints. Based on John's constraint ranking shown in (10), the goal is to demote markedness constraints such as \*FRICATIVES, \*LIQUID-[r], \*LIQUID-[l], and \*CODA to below the faithfulness constraints with which they conflict. Therefore, possible treatment targets are (not surprisingly) fricatives, liquids, and final consonants.

### Preliminary Target Selection

It is possible to address the demotion of several constraints at once by selecting, for example, fricative + liquid clusters such as /fr-/ and /fl-/, in words such as *fruit*, *fries*, *fly*, and *flag*. Recall that fricative + liquid clusters were reduced to liquid or glide singletons in John's productions. It is expected that, following treatment on such clusters, \*FRICATIVES, \*LIQUID-[r], and \*LIQUID-[l] would be demoted, as in (11).

(11) Treat /fl-/ and /fr-/

DEP >> MAX, \*CODA, IDENT-[continuant], IDENT-[consonantal] >> \*COMPLEX, \*FRICATIVES, \*LIQUID-[l], \*LIQUID-[r]

This is not a novel approach to target selection. In fact, phonological process analysis might lead to a similar target selection, based on John's errors on clusters (Ingram, 1981; Shriberg & Kwiatkowski, 1980). Typically, phonological process analysis involves determining the more frequently occurring patterns in a child's productions. For John, cluster reduction is one such process; accordingly, consonant clusters would be targeted for remediation. A more in-depth phonological process analysis also might reveal that the process of cluster reduction affects only fricative clusters. Thus, fricative clusters in particular would be targeted for remediation.

Notice, however, that this choice of treatment targets would not have any impact on \*COMPLEX because it is ranked low already and consonant clusters already are allowed by John's grammar. In other words, \*COMPLEX does not need to be demoted in John's grammar. Note also that treatment on /fl-/ and /fr-/ clusters would not be expected to have any impact on John's production of coda consonants because it is not expected that \*CODA would be demoted. It is expected that variable final consonant deletion would continue following treatment on /fl-/ and /fr-/. In other words, the analysis within optimality theory revealed that consonant clusters are not problematic for John; rather, fricatives are. Thus, treatment on clusters may not be most appropriate for yielding the desired demotion of markedness constraints.

### Recommended Target Selection

An alternative treatment strategy might target the singletons /f/, /r/, and /l/ in final position (in words such as *knife*, *cough*, *car*, *bear*, *ball*, and *hill*), thereby attempting to demote all four markedness constraints, \*FRICATIVES, \*LIQUID-[r], \*LIQUID-[l], and \*CODA. These goals are based on the more focused analysis within optimality theory that



revealed which structures were truly problematic in John's grammar. In this case, clusters need not be targeted. In fact, treatment on /f/, /r/, and /l/ in final position is expected to cause improvement indirectly on the fricative + liquid clusters because clusters already are allowed by John's grammar, and because the nature of the error with the clusters is due to \*FRICATIVES. Following treatment on final /f/, /r/, and /l/, \*FRICATIVES, \*LIQUID-[r], \*LIQUID-[l], and \*CODA would be demoted below the faithfulness constraints with which they interact. This is shown in (12), where all faithfulness constraints outrank the relevant markedness constraints. This ranking goal is consistent with the target grammar, as shown for the words *sled* and *clown* in the tableau in Figure 16.

(12) Treat /f/, /r/, and /l/ finally

DEP, MAX, IDENT-[continuant], IDENT-[consonantal] >> \*COMPLEX, \*FRICATIVES, \*LIQUID-[l], \*LIQUID-[r], \*CODA

A variety of experimental treatment efficacy studies already have established that introducing marked structure into a child's phonological system results in the greatest system-wide change (for a review, see Gierut, 1998, 2001). Specifically, demoting \*FRICATIVES in John's grammar will allow for all fricatives to occur target appropriately, and demoting \*LIQUID-[r] and \*LIQUID-[l] should allow liquids to occur correctly (within-class change, as reported in, e.g., Elbert & McReynolds, 1978; Hoffman, 1983; McReynolds & Elbert, 1981). Additionally, targeting marked sounds within marked contexts that are most difficult for the child (i.e., final position) may generalize to unmarked, easier structures, causing improvement in other untreated sounds (across-class change, as reported in, e.g., Dinnsen, 1984; Dinnsen & Elbert, 1984; Gierut, Elbert, & Dinnsen, 1987; Gierut, Morrisette, Hughes, & Rowland, 1996). Targeting these sounds in final position should allow treated and untreated final consonants to occur less variably (Elbert & McReynolds, 1978, 1985; Weiner, 1981). Furthermore, a variety of treatment studies have established that targeting a sound for treatment in one context will result in generalization across contexts, even for fricatives and liquids (see Elbert & McReynolds, 1975, 1978; Hoffman, 1983). For instance, Elbert and McReynolds (1975) found that targeting an allophone of /r/ in one context (e.g., [ʁ]) generalized to production of /r/ allophones in other contexts (e.g., [tr-]). Thus, even in cases where allophones of a given phoneme are phonetically different from one another (as with /l/ and /r/ allophones), generalization across word positions still may occur. Therefore, it is predicted that targeting final /f/, /r/, and /l/ should result in improvements across contexts in John's phonology. Moreover, /l/ is most difficult for John in final position because it is never produced correctly in that context (but does occur in other contexts), whereas /f/ and /r/ are difficult in all contexts. Treatment research suggests that targeting the least known (most difficult) aspects of the target sound system, in this case /f/, /r/, and /l/ word-finally, will result in the greatest system-wide change (Elbert, Dinnsen, & Powell, 1984; Gierut et al., 1987). It is predicted that these revised

Figure 16. Ranking goal: Faithfulness constraints outrank markedness constraints.

	DEP	MAX	IDENT-[cont]	IDENT-[cons]	*COMP	*FRIC	*LIQ-[r]	*LIQ-[l]	*CODA
<i>/klaʊn/ clown</i>									
a.  [klaʊn]					*			*	*
b. [kwaʊn]				*!	*				*
c. [kaʊn]		*!							*
d. [laʊn]		*!						*	*
e. [klaʊ]		*!			*			*	
f. [kəlaʊn]	*!							*	*
<i>/sled/ sled</i>									
a.  [slɛd]					*	*		*	*
b. [swɛd]				*!	*	*			*
c. [tlɛd]			*!		*			*	*
d. [sɛd]		*!				*			*
e. [lɛd]		*!						*	*
f. [slɛ]		*!			*	*		*	
g. [səlɛd]	*!					*		*	*

treatment goals will result in extensive change across John's sound system.

## CONCLUSION

To summarize, John produces unmarked forms that are attributable to high-ranking markedness constraints, as do most children at some point in development. In particular, \*FRICATIVES and \*LIQUID-[r] are ranked relatively high in his grammar. At the same time, some intra- and interword variation is apparent with other production patterns. Such variation is attributed to equal ranking of other constraints for patterns of final consonant deletion and gliding of /l/, and constraint interaction for cluster reduction. This account is especially revealing of the true nature of John's cluster reduction pattern, which actually was due not to restrictions on syllable structure (\*COMPLEX), but rather to the nature of the segments that made up the cluster (\*FRICATIVES).

This type of analysis has allowed for an in-depth characterization of a phonological system, which in turn has allowed for more focused treatment programs for children such as John. Within the framework of optimality theory, treatment is aimed at demoting markedness constraints below faithfulness constraints through the introduction of marked structure. Targeting the most complex, marked aspects of the sound system is predicted to cause substantial change in John's grammar.

One outstanding issue relates to treatment target selection when constraints are ranked equally with one another. Perhaps this equal ranking reflects a transitional point in a child's development, such that the markedness constraints are in the process of being demoted in the grammar. Does treatment aimed at reranking equally ranked constraints result in the same kind of change in a child's overall sound system as treatment aimed at constraints that are not ranked equally? In previous research by Gierut and colleagues (1987), it was determined that remediation on obligatory error patterns (0% accuracy for affected sounds) resulted in significant system-wide improvement, whereas treatment on optional error patterns (affected sounds occurred with some degree of accuracy) resulted in limited change. Because optional error patterns may reflect equally ranked constraints within an optimality theory perspective, targeting equally ranked constraints in therapy may cause only limited change in a child's overall sound system. This remains to be tested empirically.

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