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# Optimality Theory in Phonological Acquisition

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This tutorial presents an introduction to the contemporary linguistic framework known as optimality theory (OT). The basic assumptions of this constraint-based theory as a general model of grammar are first outlined, with formal notation being defined and illustrated. Concepts unique to the theory, including “emergence of the unmarked,” are also described. OT is then examined more specifically within the context of phonological acquisition. The theory is applied in descriptions of children’s common error patterns, observed inter- and intrachild variation, and productive change over time. The particular error patterns of fronting, stopping, final-consonant deletion, and cluster simplification are considered from an OT perspective. The discussion concludes with potential clinical applications and extensions of the theory to the diagnosis and treatment of children with functional phonological disorders.

**KEY WORDS:** optimality theory, linguistic theory, phonological acquisition, phonological disorders

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**F**ormal theories of language have been central in shaping our understanding of the acquisition process, whether normal or disordered. The assumptions and claims of these models vary widely, often leaving open the question of a theory’s explanatory adequacy. In this regard, a well-defined set of criteria have been advanced to evaluate the dual adequacy of any linguistic theory as also a theory of phonological acquisition (Ferguson & Garnica, 1975). Specifically, an adequate theory of phonological acquisition must at least account for the following: (a) the actual facts of children’s productions and the mismatches between a child’s output and the adult input forms; (b) the generalities that span children’s sound systems, as well as associated variability within and across developing systems; and (c) the changes that occur in children’s grammars over time. In achieving these goals, an adequate theory must also remain testable and falsifiable.

The purpose of this paper is to revisit these three criteria by considering optimality theory (hereafter, OT; McCarthy & Prince, 1994, 1995; Prince & Smolensky, 1993) as a viable theory of phonological acquisition. OT is the most contemporary linguistic framework advanced to date, with recent extensions to development. It is remarkably unique in its assumptions and claims, standing apart from the conventions of earlier frameworks that have long held prominence in the linguistic literature. OT aligns with connectionist frameworks of cognitive and computer sciences, and consequently, integrates language with cognition in modeling patterns of sound systems. Our appeal to the three criteria advanced by Ferguson and Garnica will allow us to evaluate the explanatory adequacy, but not the exegetic adequacy, of OT. That is, we

will not yet advance OT as superior to other theories; instead, we offer OT in tandem with existing theories as an adequate account of phonological acquisition. We underscore the necessity for the simultaneous appeal to multiple theories and their application to assessment and treatment of phonological disorders until one perspective emerges as superior.

In this tutorial, we begin with an overview of the basic premises, predictions, and conventional notations of OT. The particular version of OT that is described is *correspondence theory* (McCarthy & Prince, 1995). It is the most prevalent perspective being developed in the literature and differs to varying degrees from other proposals, both in terminology and formalism (e.g., Bernhardt & Stemberger, 1998; Clements, 1995; Golston, 1996; Lacharite & Paradis, 1993; Prince & Smolensky, 1993). Then OT is examined as a viable account of phonological acquisition in its ability to capture children's error patterns, inter- and intrachild variability, and longitudinal change in children's productions. The discussion concludes with possible clinical applications and extensions of OT to the diagnosis and treatment of functional phonological disorders as a means of empirically testing (and potentially falsifying) the theory. We will speculate about potentially new insights into long-term problems about acquisition; however, given the infancy of OT, these remain to be fully explored in future research.

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## Basics of OT

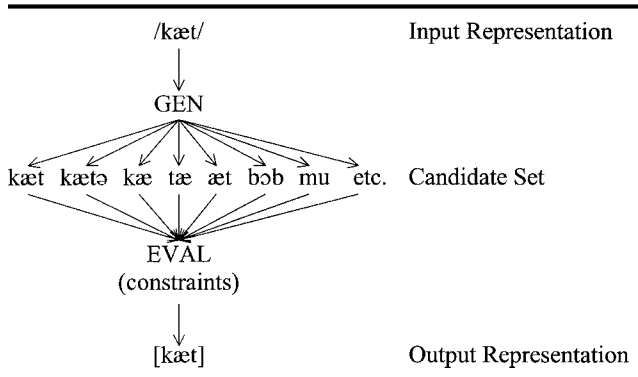
### *Model of the Grammar*

One major goal in the field of phonology is to compare speakers' competence to their performance. That is, phonologists explore what speakers know about their language and compare that to what the speakers actually say. The discrepancies between competence and performance are often dramatic, and the goal of phonological theory is to provide an explanation for such discrepancies. Part of the explanation relates to determining *mental representations* and *surface representations*. It is generally assumed that a speaker of a given language has some mental representation for a given word or sound, but sometimes that word has a very different surface representation. The mental representation includes unpredictable and contrastive information in the language. The surface representation, on the other hand, contains predictable, noncontrastive information. The goal of *generative phonology* is to account for how a grammar gets from the mental representation to the surface representation. Many generative phonology frameworks have accounted for this difference between mental and surface representations in terms of a *derivation* (e.g.,

Chomsky & Halle, 1968; Goldsmith, 1990; Kiparsky, 1982). These derivational frameworks assume intermediate levels of representation operated on by rules to yield the corresponding surface representation. Rules apply in a serial fashion; that is, each rule applies one at a time in a particular and fixed order. The rules and the order in which they apply constitute the grammar, along with mental and surface representations.

The recent advancement of OT has prompted a new view of generative phonology and how grammars yield surface representations from mental representations. Whereas previous frameworks have been largely derivational in nature, OT assumes a different organization of the grammar. Mental and surface representations are still assumed to exist, but they are referred to as *input* and *output representations*, respectively. Furthermore, how the grammar yields the output representation from the input representation is crucially different from that of derivational frameworks. Instead of rules, there are *constraints*. These constraints, ranked in a particular order, determine which output is most harmonic with the grammar. A surface/output form is considered *harmonic* or *optimal* when it is determined to be the output form that best satisfies the constraints and their relative rankings. The relation between the input representation and the output representation is mediated by two entities in OT, defined in (1): GEN (generator) and EVAL (evaluator). Given an input representation, GEN generates a potentially infinite number of possible output candidates. For example, for the target word "cat," outputs would include forms similar to the input, such as [kæt], [kæ], and [tæ], as well as less similar forms such as [bɒb] and [mu]. It is the job of EVAL to determine which candidate is most harmonic with the grammar. EVAL chooses the most optimal output by considering a set of universal constraints (CON). These constraints are ranked in a language-specific order. This allows for each language to have its own ranking, thereby permitting variation in the types of grammars that are observed. One crucial aspect of this framework is that constraints are *violable*. In other words, it is possible for a grammar to choose as optimal a candidate that does not satisfy every constraint. In fact, every possible output form will violate some constraint of the grammar. However, in a given language, certain constraints are more important than others. Violations of those more important constraints will be more serious than violations of less important constraints. Moreover, each candidate is evaluated by all constraints at once in parallel, rather than in the serial fashion of derivational frameworks. The candidate that violates the fewest high-ranked constraints will be chosen as optimal by the grammar. A schematic of the grammar within OT is shown in Figure 1.

Figure 1. Schematic of the grammar within OT.



(1) Formal model of OT (adapted from Archangeli, 1997)

- GEN: Given an input representation, GENERator provides a set of potential output forms.
- EVAL: Given the candidate set created by GEN, EVALuator chooses the most optimal or harmonic output for the given input representation.
- CON: A language-specific ranking of a universal set of CONstraints is used by EVAL in determining the optimal output form.

### Nature of Constraints

In this tutorial, we will define and illustrate specific constraints that have been drawn directly from OT and the study of fully developed languages (e.g., McCarthy & Prince, 1995), illustrating how they may be appealed to in accounting for developing systems. Constraints are of two basic types: faithfulness constraints and markedness constraints as in (2). *Faithfulness constraints* ensure that output representations resemble input representations. Therefore, these constraints require that all the segments in the input will be parsed in the output. *Parse* means that a segment in the input representation surfaces in the output representation. The specific constraint MAX requires that all segments be parsed. Given an input /kæt/, the output form [kæ] would be in violation of the constraint MAX because the /t/ of the input representation is not parsed into the output representation. Faithfulness constraints also require that all the segments in the output be present in the input, thus preventing the insertion of segments. The specific constraint DEP prevents insertion. Given an input /kæt/, the output form [kætə] would be in violation of DEP because the [ə] in the output is not part of the input representation.

(2) Examples of faithfulness and markedness constraints (McCarthy & Prince, 1995)

- MAX: Segments in the input must correspond to segments in the output. (No deletion.)
- DEP: Segments in the output must correspond to segments in the input. (No insertion.)
- IDENT[FEAT]: The place, voice, and manner features of segments of the input must surface in the corresponding segments in the output.
- \*COMPLEX: Avoid consonant clusters.

In addition, certain faithfulness constraints prevent a word such as “cat” from surfacing as [bɒb] because such an output form does not resemble the input form /kæt/ except in terms of the number of segments. Whereas MAX and DEP refer to *segmental faithfulness*, the constraint IDENT refers to *featural faithfulness*. The output form [bɒb] would satisfy DEP and MAX in terms of segmental faithfulness: There are three segments in the input in the form consonant-vowel-consonant and three segments in the output also in the form consonant-vowel-consonant. Clearly though, [bɒb] is in serious violation of faithfulness in a featural sense. The voiceless velar stop /k/ in the input is a voiced bilabial stop [b] in the output. The voiceless alveolar stop /t/ in the input is also a [b] in the output. The low front unrounded vowel [æ] in the input is a mid back rounded vowel [ɔ] in the output. This “unfaithfulness” in terms of place and voicing between segments constitutes violations of constraints such as IDENT-PLACE and IDENT-VOICE. These constraints require that features (rather than segments) in the input must also be present in the output. Faithfulness constraints such as the aforementioned are central tenets of OT: They have been shown to have cross-linguistic validity in that they account for a variety of independently motivated patterns (e.g., McCarthy & Prince, 1995).

*Markedness constraints* (alternatively referred to as well-formedness or structural constraints) are equally central to OT and have likewise been shown to account for many phenomena cross-linguistically. These constraints require that output forms be unmarked in structure. Generally, *markedness* refers to the complexity of a given structure relative to another structure, as determined by, for example, language typologies, frequency of occurrence, and order of acquisition facts (Cairns, 1969; Greenberg, 1965; Hawkins, 1987; Jakobson, 1968; Maddieson, 1984). Unmarked properties of language are those structures that are considered to be most basic because they are present in all grammars. Although markedness considerations are taken into account in all linguistic theories, OT is one of the few frameworks that

incorporates markedness directly into the grammar. This is important because structural considerations that were formerly external are now presumed to be internal to Universal Grammar. To illustrate, a markedness relationship exists between consonant clusters and singletons. All languages allow unmarked singletons to occur, but not all languages allow more marked consonant clusters to occur. Within OT, the constraint \*COMPLEX is a particular markedness constraint that prohibits forms with consonant clusters. The possible output form [plei] “play” incurs a violation of \*COMPLEX because it contains the consonant cluster [pl-]. This means that [plei] is a marked output form in comparison to, for example, [peɪ], which contains a consonant singleton and therefore does not incur a violation of \*COMPLEX.

The relationship between faithfulness and markedness constraints comes in their violability. Not all faithfulness constraints are satisfied at all times, leading to differences between input and output forms. Similarly, not all markedness constraints are satisfied at all times, allowing typologically more marked forms to occur in certain circumstances. In essence, faithfulness constraints and markedness constraints are antagonistic: Faithfulness constraints may be violated in order to satisfy high-ranking markedness constraints, or markedness constraints may be violated in order to satisfy high-ranking faithfulness constraints.

Because constraints are assumed to be innate, part of Universal Grammar, and therefore universal to all languages, the way in which variation across languages is accounted for is in terms of the relative ranking of constraints. A particular constraint may be high ranked in one language, but low ranked in another. Take again the occurrence of consonant clusters. In English, consonant clusters occur, but in the language Fijian, for example, they do not (Schütz, 1980). In comparing English with Fijian, the presence versus absence of consonant clusters is attributable to the relative ranking of the constraint \*COMPLEX, which prohibits clusters. In English, \*COMPLEX must be ranked low, and violation of it is not serious. However, in Fijian, the very same constraint must be ranked high to ensure that optimal output forms do not violate it.

One important research issue that remains relates to the number and types of constraints that may be available as part of Universal Grammar. Archangeli (1997) suggests this can best be addressed through broad-based demonstrations that specific constraints are crucial in accounting for phonological patterns of many languages in many different domains, thereby differentiating the universal from other potentially ad hoc constraints that are applicable only in isolated and limited cases. The disambiguation of universal from ad hoc constraints continues to be debated and elaborated in the

literature (e.g., Eisner, 1997; Lombardi, 1998). As stated previously, this tutorial considers in our analyses of developing systems only those constraints that have received wide cross-linguistic validation across phonological phenomena in fully developed systems.

### Formalism of OT

Within formal OT, possible output candidates, relevant constraints, and the relative ranking of constraints are incorporated into what is referred to as a *constraint tableau*. To best illustrate tableau formalism, consider a hypothetical language in which a hypothetical markedness constraint \*D is ranked higher than another hypothetical faithfulness constraint FAITH-D. The markedness constraint prohibits the occurrence of some segment [D], whereas the faithfulness constraint requires that if /D/ occurs in the input, it must also occur in the output. The ranking of these two constraints relative to each other is formally expressed with double right-angled brackets, as in (3). (Note that constraints are typically abbreviated in capitals.)

#### (3) Hypothetical Language 1: \*D >> FAITH-D

In a sample tableau shown in (4), a given input form of this hypothetical language, /ABCD/, is shown in the upper left cell. Possible output candidates provided by GEN are listed below the input form in the candidate column, with Candidate (a) [ABCD] and Candidate (b) [ABC] being considered. (Although GEN is assumed to provide an infinite number of possible candidates, only two candidates are shown here for explication purposes.) The constraints are ranked in order across the top of the tableau from highest (in the leftmost column after the candidate column) to lowest (in the rightmost column). This order follows from the double-bracket ranking notation in (3). In any tableau, an asterisk (\*) indicates violations of constraints by candidates. Some violations are *fatal violations*—that is, they constitute violations serious enough to prevent a given candidate from being chosen as optimal. An asterisk followed by an exclamation point (!) indicates fatal violations. The manual indicator (☞) marks the winning or most harmonic candidate (i.e., the true output form), which is the output form that best satisfies the constraint ranking in comparison to all other potential candidates.

#### (4) Hypothetical Language 1: /ABCD/ → [ABC]

	/ABCD/	*D	FAITH-D
a.	ABCD	*!	
b.	☞ ABC		*


Given OT formalism, the tableau in (4) can be interpreted as a comparison of the hypothetical input representation /ABCD/ relative to two possible output forms. For Candidate (a), all segments of the input /ABCD/ are present in the output [ABCD]. This candidate is wholly faithful to the input, meaning that the lower ranked faithfulness constraint FAITH-D is satisfied. However, because Candidate (a) includes the segment [D], it does incur a violation of the higher ranked markedness constraint \*D. Turning to Candidate (b), notice that segment /D/ from the input is missing in the output [ABC] (i.e., /D/ is not parsed). Because [D] is not present in this output form, Candidate (b) incurs a violation of the faithfulness constraint FAITH-D. At the same time, Candidate (b) does satisfy the markedness constraint against the occurrence of [D]. To determine how Candidate (a) fares relative to (b) as an optimal output, the relative ranking of constraints and their violations must be considered in tandem by EVAL. Recall that \*D is ranked higher than FAITH-D; consequently, a violation of \*D is a more serious offense to the grammar than a violation of FAITH-D. Because Candidate (a) violates this highest ranking constraint, the violation is considered fatal, as indicated by the exclamation point. The grammar thus chooses Candidate (b) as the most harmonic output as denoted by the manual indicator. Note that shading is used in the column under FAITH-D. In OT tableaux, shading under a certain constraint shows that violations of that constraint are not crucial to determining the optimal output. Specifically, in this example, the fact that Candidate (a) violated highest ranking \*D, but Candidate (b) did not, was enough evidence for the grammar to choose Candidate (b) as the winning output. The violation of FAITH-D by Candidate (b) is, in a sense, irrelevant to optimal candidate selection.

As a further illustration, consider a second hypothetical language in which the same constraints are operative, but ranked in the reverse order, as in (5).

(5) Hypothetical Language 2: FAITH-D >> \*D

The tableau in (6) shows the same input and output candidates as before. The same constraints are incorporated, and even the same violations are incurred: Candidate (a) violates \*D, and Candidate (b) violates FAITH-D. However, because the constraints are ranked differently, Candidate (b) incurs the higher ranked, fatal violation and loses out to the optimal Candidate (a).

(6) Hypothetical Language 2: /ABCD/ → [ABCD]

/ABCD/	FAITH-D	*D
a.  ABCD		*
b. ABC	*!	

Together, the two different tableaux illustrate two different grammars. Because OT assumes that a given grammar has one and only one ranking of constraints, the major differences that arise between languages—and even minor differences between dialects of the same language—are thus attributable to different constraint rankings.

In closing this section on the rudiments of OT, it should be mentioned that substantial evidence has amassed in support of this linguistic framework. Though the theory was initially put to test as an account of phonological phenomena related to syllable structure, syllabification, and reduplication in languages of the world, it has since been extended to other patterns (e.g., Benua, 1995; Itô & Mester, 1997; Padgett, 1995; Rosenthal, 1994; Zoll, 1997), other components of the grammar (e.g., Anderson, 1997; Grimshaw & Samek-Lodovici, 1995; Legendre, Wilson, Smolensky, Homer, & Raymond, 1995; Speas, 1995), and other populations (e.g., Broselow, Chen, & Wang, 1998; Demuth, 1995; Gnanadesikan, 1996; Guitart, 1997; Iverson & Lee, 1994; Kirchner, 1996). Also, although OT was originally developed as an outgrowth of theories of neural computation, it has already come full circle with computational models of language learnability being advanced (Hale & Reiss, 1998; Pater, 1998; Pulleyblank & Turkel, 1995; Tesar, 1997; Tesar & Smolensky, 1998). The reader is referred to Archangeli and Langedoen (1997) for a broader overview of these theoretical developments and to the Rutgers Optimality Archive on the World Wide Web (<http://ruccs.rutgers.edu/roa.html>) for more in-depth study of OT.

## OT in Phonological Acquisition

The model of the grammar as set forth by OT makes a specific proposal about the way in which the course of phonological acquisition proceeds. In particular, a child acquiring the phonology of English (or any other language) must learn items of the lexicon and also the relative ranking of universal constraints as pertains to that language (Prince & Smolensky, 1993; Seidenberg, 1997). It has long been observed that, at the earliest stages of phonological acquisition, a child's productions are simpler than those of the adult in terms of featural, segmental, and syllabic properties. Typically, a child's early productions are unmarked in structure (Jakobson, 1968). Within OT, this unmarkedness translates into differences in constraint rankings between the child and adult grammars. Specifically, markedness constraints must be high ranked in acquisition so that unmarked output forms are likely to surface in a child's speech. This claim is reflected by the predominant and accepted view that children's grammars consist of markedness constraints outranking faithfulness constraints (Demuth, 1995;

Gnanadesikan, 1996; Smolensky, 1996b). This is further said to account for the mismatch between child and adult forms. However, over time, a child's system must change to approximate the target language. This entails a reranking of constraints, with demotion of the higher ranked markedness constraints below certain faithfulness constraints. Presumably, a grammar settles into its final state of constraint ranking when it can no longer differentiate between alternative constraint rankings in their ability to generate target productions. In other words, the constraint ranking of a child's grammar may or may not correspond exactly to the ranking of the adult, but the end result is largely the same output. It is this sort of variation in constraint ranking across grammars within and across languages that is further predicted to lead to language variation and historical sound change (Turkel, 1994). The critical question though is whether this presumed course of acquisition bears out. It is in the context of this that we examine OT in phonological acquisition relative to the three criteria defined by Ferguson and Garnica (1975), namely, capturing common error patterns, allowing for individual differences, and preserving continuity in the grammar over time.

### Common Error Patterns

Three of the most common developmental error patterns reported in the literature are fronting, stopping, and final-consonant deletion (Locke, 1983). These patterns have been observed in both normally developing and phonologically disordered systems, and they may be accounted for by appealing to conflicting faithfulness and markedness constraints (McCarthy & Prince, 1995). From the perspective of OT, each of these error patterns reflects a degree of phonological unmarkedness. Specifically, coronals are unmarked relative to dorsals (Stemberger & Stoel-Gammon, 1991). In OT this is accounted for by the constraint \*DORSAL, which prevents velar segments from surfacing in the output. Stops are unmarked relative to fricatives (Ingram, 1989b) as a result of the constraint \*FRICATIVES, which prevents fricatives from surfacing. Finally, open CV syllables are unmarked relative to closed CVC syllables (Ingram, 1989b; Stemberger, 1996) because of a constraint known as \*CODA, which prohibits syllable-final consonants. As will be shown, markedness relationships of these types can be described by positing high-ranking markedness constraints over faithfulness constraints.

### Fronting

In a pattern of fronting, dorsal segments /k/ and /g/ are replaced by coronals [t] and [d], respectively, as in [ti] "key" or [dou] "go." An OT account of this error pattern would require positing the high-ranking markedness constraint, \*DORSAL, as in (7). This constraint would be

ranked above a faithfulness constraint requiring that the input representation directly resemble the output representation. In this case, IDENT-PLACE ensures that place of articulation in the input is also preserved in the output. Notice the antagonistic nature of the markedness constraint relative to the faithfulness constraint.

- (7) \*DORSAL: Avoid dorsal segments.  
 IDENT-PLACE: Preserve place features from input segments.  
 Ranking: \*DORSAL >> IDENT-PLACE

The tableau in (8) illustrates this relationship for the target word "key." By ranking \*DORSAL above IDENT-PLACE, the grammar ensures that the less marked form, Candidate (b), will be the optimal output. Candidate (a), the faithful, target-appropriate output form for input /ki/, incurs a fatal violation of \*DORSAL because a dorsal segment [k] is in that output form. This candidate, however, satisfies IDENT-PLACE because all the segments of the output retain the same place of articulation as their corresponding input segments. Candidate (b), on the other hand, satisfies \*DORSAL because there is no dorsal segment [k] in the candidate form. Yet this candidate does violate IDENT-PLACE because the /k/ of the input corresponds to a [t] in the output. Because \*DORSAL is ranked higher than IDENT-PLACE, a violation of the higher ranked constraint is considered fatal. This leaves Candidate (b) as the more harmonic candidate, and the grammar chooses [ti] as the optimal form, despite its violation of lower ranked IDENT-PLACE. Thus, for a child who presents a pattern of fronting, it is more important that dorsals be prevented from surfacing than it is for underlying place of articulation to be preserved. This reflects the relatively marked status of dorsal place in acquisition, and illustrates the ranking relationship of markedness over faithfulness constraints in children's grammars.

(8) Fronting: /ki/ → [ti]

	/ki/ "key"	*DORSAL	IDENT-PLACE
a.	ki	*!	
b.	ti		*

### Stopping


The error pattern of stopping involves the substitution of stops for target fricatives, as in [teɪ] "say" or [du] "zoo." An OT description of this pattern requires that a markedness constraint against fricatives, \*FRICATIVES, be highest ranked as in (9). This markedness constraint, in turn, must dominate a lower ranked faithfulness constraint, IDENT-MANNER, which requires

that manner of articulation be preserved from the input to the output.

- (9) \*FRICATIVES: Avoid fricatives.  
 IDENT-MANNER: Preserve input manner features.  
 Ranking: \*FRICATIVES >> IDENT-MANNER

In (10), the pattern of stopping is illustrated in a tableau for the target word “say” and the constraint ranking of \*FRICATIVES over IDENT-MANNER. Candidate (b) [teɪ] will always be more harmonic than the more faithful Candidate (a) [seɪ] because it is more important for fricatives to be prevented from surfacing than it is for manner of articulation to be preserved, as dictated by the constraint ranking. Specifically, Candidate (a) incurs a fatal violation of high-ranked \*FRICATIVES, while satisfying IDENT-MANNER. In comparison, Candidate (b) violates IDENT-MANNER, but satisfies higher ranked \*FRICATIVES. As in the pattern of fronting, a child who evidences stopping will opt for unmarked properties of the grammar.

(10) Stopping: /seɪ/ → [teɪ]

/seɪ/ “say”	*FRICATIVES	IDENT-MANNER
a. seɪ	*!	
b.  teɪ		*


## Final-Consonant Deletion

In the case of final-consonant deletion, target-syllable structure of the shape CVC, such as /kæt/ “cat,” is realized as unmarked CV structure, as in [kæ]. The final /t/ will not surface if a child’s grammar has a high-ranked markedness constraint against CVC syllables. This constraint, \*CODA, prohibits syllables from being closed by consonants, as in (11). \*CODA must be ranked higher than the faithfulness constraint, MAX, which requires that all segments from the input surface in the output. In this grammar, because \*CODA is ranked higher than MAX, it is better for an open syllable to surface than it is for the segments to be parsed.

- (11) \*CODA: Syllables do not have codas.  
 MAX: Segments in the input must correspond to segments in the output. (No deletion.)  
 Ranking: \*CODA >> MAX

The tableau in (12) shows this relationship for the target word “cat.” A fatal violation of \*CODA by the faithful Candidate (a) allows for the unfaithful Candidate (b) to surface with /t/ unparsed. Ranking markedness over faithfulness constraints again yields unmarked structure as the optimal output form for the pattern of final-consonant deletion.

(12) Final-consonant deletion: /kæt/ → [kæ]

/kæt/ “cat”	*CODA	MAX
a. kæt	*!	
b.  kæ		*

In addition to these common error patterns, a number of other prevalent patterns in children’s speech have been described within an OT framework (e.g., Barlow, 1997; Barlow & Dinnsen, 1998; Bernhardt & Stemberger, 1998; Demuth, 1997; Dinnsen & Barlow, 1998a, 1998b; Goad, 1998; Lléo, 1996; Ohala, 1996; Ota, 1998; Pater, 1997; Smolensky, 1996a, 1996b; Stemberger, 1996; Velleman, 1996). Interestingly, all these acquisition accounts have involved conflicts between markedness and faithfulness, with markedness dominating. At first glance, this may give the impression that all children’s grammars will be the same within OT, but clearly, there is variation within and across developing phonological systems.

## Individual Differences

Interchild variability has posed a long-standing problem for theories of phonological acquisition. The issue is how to rectify overwhelmingly common production patterns with those that are unique to specific children. Many interpretations of this tension between universal versus child-specific properties in phonological acquisition have been offered (Dinnsen, 1992; Goad & Ingram, 1987; Ingram, 1992; Macken & Ferguson, 1983), with OT being no exception. Consistent with the proposed model of the grammar, variation across children’s systems is attributed to the differential ranking of constraints. To illustrate the way in which individual differences may emerge within OT, we consider another common error pattern that relates to the development of onset consonant clusters.

Generally, singletons are acquired before onset clusters across developing systems (Jakobson, 1968). A child necessarily passes through a stage in which target clusters are produced incorrectly. However, a given child’s incorrect production of clusters may take any number of different forms, with at least three possible patterns observed in the literature: reduction, epenthesis, and coalescence (Chin, 1993; Chin & Dinnsen, 1992; Edwards & Shriberg, 1983; Greenlee, 1974; Ingram, 1989a; Smit, 1993). *Reduction* is the case of a target cluster surfacing as a single segment of the multiple element unit, as for example, “swing” being produced as [sɪŋ], with the segment /w/ being omitted. *Epenthesis* involves the insertion of a vowel between the target cluster, as in “swing” being realized as [səwɪŋ]. *Coalescence* is when a target cluster is realized as a singleton, but that substitute is not either one of the segments of the

target cluster; rather, it is a segment that shares properties of the cluster in terms of place and manner of articulation. Here, “swing” may be produced as [fiŋ]: [f] shares the manner of frication with /s/ and the labial place with [w] of the /sw-/ cluster. Although these cluster simplification patterns stand apart, they can all be accounted for within OT by the relative and differential ranking of four shared constraints: \*COMPLEX, MAX, DEP, and UNIFORMITY, defined in (13).

- (13) \*COMPLEX: Avoid consonant clusters.  
 MAX: Segments in the input must correspond to segments in the output. (No deletion.)  
 DEP: Segments in the output must correspond to segments in the input. (No insertion.)  
 UNIFORMITY: Output segments may not have multiple correspondents in the input. (No coalescence.)

## Reduction

For a child who reduces clusters to singletons, it is clear that the constraint against syllables beginning with clusters, \*COMPLEX, must be highly ranked. This constraint, however, does not account for the precise way in which target clusters will be reduced. To uniquely account for reduction to a single segment, it is necessary to posit other equally high-ranking constraints that prevent alternative patterns of epenthesis (i.e., DEP) or coalescence (i.e., UNIFORMITY), in addition to a lower ranking constraint that prevents deletion (i.e., MAX). The potential ranking is shown in (14), along with a corresponding tableau illustrating the pattern of reduction in (15).<sup>1</sup>

- (14) \*COMPLEX, DEP, UNIFORMITY >> MAX

In evaluating each candidate of the tableau in (15), note that the faithful Candidate (a) incurs a fatal violation of \*COMPLEX because of the target-appropriate [sw-] cluster. Candidate (c) also incurs a fatal violation of DEP because of the insertion of schwa between the target cluster. Likewise, Candidate (d) incurs a fatal violation of UNIFORMITY because of the coalesced [f] in place of the /sw-/ cluster. In contrast, Candidate (b) only incurs a violation of lowest ranked MAX because it does not segmentally correspond to the input. Candidate (b) does

<sup>1</sup>In this, and the examples that follow, some additional OT formalism requires use and explanation. In particular, when constraints are equally ranked, a comma is used in the double-bracket ranking notation (e.g., \*COMPLEX, DEP, UNIFORMITY >> MAX). The equal ranking of constraints is also reflected in the tableau by *dashed*, as opposed to *solid*, columnar lines separating constraints. *Subscript indices* are used in the tableau to denote correspondences between specific input and output segments, particularly relevant notation in cases of coalescence.

not violate any other of the higher ranked constraints; thus, it is chosen as most harmonic. Note that another possible output candidate [wiŋ] is equally optimal if only these four constraints are considered. Additional constraints that appeal to the relative sonority of sounds are required to determine if [wiŋ] is more harmonic than [siŋ]. This will likewise be the case in examples of later sections where, for ease of exposition, the full range of possible candidates is not considered relative to the full range of applicable constraints (for discussion, see Barlow, 1997; Barlow & Dinnsen, 1998).

The particular ranking of constraints for the pattern of reduction therefore predicts that, for a grammar that allows cluster reduction, it is a less serious violation to delete a segment (i.e., Candidate (b)) than it is to allow a cluster to surface (i.e., Candidate (a)), a segment to be inserted (i.e., Candidate (c)), or coalescence to occur (i.e., Candidate (d)).

- (15) Cluster reduction: /swiŋ/ → [siŋ]

	/s <sub>1</sub> w <sub>2</sub> i <sub>3</sub> ŋ <sub>4</sub> / “swing”	*COMPLEX	DEP	UNIFORMITY	MAX
a.	s <sub>1</sub> w <sub>2</sub> i <sub>3</sub> ŋ <sub>4</sub>	*!			
b.	☞ s <sub>1</sub> i <sub>3</sub> ŋ <sub>4</sub>				*
c.	s <sub>1</sub> əw <sub>2</sub> i <sub>3</sub> ŋ <sub>4</sub>		*!		
d.	f <sub>1,2</sub> i <sub>3</sub> ŋ <sub>4</sub>			*!	

## Epenthesis


For a child who exhibits epenthesis, the relative ranking of the same four constraints, \*COMPLEX, DEP, MAX, and UNIFORMITY still accounts for the pattern. In contrast to the prior case of reduction where MAX was ranked low, epenthesis requires that MAX be ranked high, as deletion (MAX) is not an option for dealing with illicit structure in this grammar. DEP must be a lower ranked constraint because insertion is apparently a less serious violation in this case. The possible ranking of constraints is shown in (16) and illustrated in the tableau in (17).

- (16) \*COMPLEX, MAX, UNIFORMITY >> DEP

As in the prior case of reduction, Candidate (a) incurs a fatal violation of high-ranked \*COMPLEX because of the [sw-] output sequence, and Candidate (d) incurs a fatal violation of high-ranked UNIFORMITY because of the [f] in the output. Candidate (b) also incurs a fatal violation of MAX because all segments of the input are not present in the output. Candidate (c) is deemed optimal because it conforms with \*COMPLEX in that there is no onset cluster, with MAX in that all segments of the input match the output, and with UNIFORMITY in that there is no coalescence. The only constraint violation that Candidate (c) incurs is

for lowest ranked DEP because there is insertion of a schwa in the output form. In the case of epenthesis then, it is a less serious violation of the grammar to insert a segment (i.e., Candidate (c)) than it is for a cluster to surface (i.e., Candidate (a)), a segment to go unparsed (i.e., Candidate (b)), or two segments to coalesce (i.e., Candidate (d)).

(17) Epenthesis: /swɪŋ/ → [səwɪŋ]

/s <sub>1</sub> w <sub>2</sub> ɪ <sub>3</sub> ŋ <sub>4</sub> / "swing"	*COMPLEX	MAX	UNIFORMITY	DEP
a. s <sub>1</sub> w <sub>2</sub> ɪ <sub>3</sub> ŋ <sub>4</sub>	*!			
b. s <sub>1</sub> ɪ <sub>3</sub> ŋ <sub>4</sub>		*!		
c.  s <sub>1</sub> əw <sub>2</sub> ɪ <sub>3</sub> ŋ <sub>4</sub>				*
d. f <sub>1,2</sub> ɪ <sub>3</sub> ŋ <sub>4</sub>			*!	


### Coalescence

A child who presents with coalescence for target clusters relies on the same four constraints, but now UNIFORMITY is ranked lowest, and the remaining three constraints, \*COMPLEX, MAX, and DEP, are ranked higher as in (18).

(18) \*COMPLEX, MAX, DEP >> UNIFORMITY

As shown in the tableau in (19), Candidates (a) and (b) incur fatal violations of the high-ranked constraints \*COMPLEX and MAX, respectively, given the occurrence of clusters and the segmental mismatch between input and output forms. Candidate (c) fatally violates DEP because of schwa insertion. These candidates are less optimal than Candidate (d) because they each violate the most highly ranked constraints. Candidate (d) is selected as most harmonic because it only violates lower ranked UNIFORMITY. For a child who presents with coalescence, it is a less serious violation of the grammar to coalesce segments (i.e., Candidate (d)) than it is for a cluster to surface (i.e., Candidate (a)), for a segment to go unparsed (i.e., Candidate (b)), or for a segment to be inserted (i.e., Candidate (c)). Other coalesced output forms would also be predicted to occur. Such forms, however, would be considered by the grammar as less harmonic than [fɪŋ] because of properties of IDENT and the observed preference for labial over other places of articulation (see Barlow, 1997; Gnanadesikan, 1996).

(19) Coalescence: /swɪŋ/ → [fɪŋ]

/s <sub>1</sub> w <sub>2</sub> ɪ <sub>3</sub> ŋ <sub>4</sub> / "swing"	*COMPLEX	MAX	DEP	UNIFORMITY
a. s <sub>1</sub> w <sub>2</sub> ɪ <sub>3</sub> ŋ <sub>4</sub>	*!			
b. s <sub>1</sub> ɪ <sub>3</sub> ŋ <sub>4</sub>		*!		
c. s <sub>1</sub> əw <sub>2</sub> ɪ <sub>3</sub> ŋ <sub>4</sub>			*!	
d.  f <sub>1,2</sub> ɪ <sub>3</sub> ŋ <sub>4</sub>				*

Taken together, these three different types of cluster simplification may correspond to three different grammars. This allows different children to exhibit different erred outputs within an OT framework. Importantly, what is common across the grammars is that children's productions are simpler (unmarked) relative to the adult. Moreover, the very same constraints can be used to yield the different outputs. This is one way that OT differs from derivational frameworks, which would likely require positing three unique rules/processes for each of the three cluster errors. The further consequence is that a unified typology of constraint rankings emerges, as in (20), to capture the seemingly different ways in which children simplify clusters.

(20) Typology of cluster simplification grammars

- a. Reduction: \*COMPLEX, DEP, UNIFORMITY >> MAX
- b. Epenthesis: \*COMPLEX, MAX, UNIFORMITY >> DEP
- c. Coalescence: \*COMPLEX, DEP, MAX >> UNIFORMITY

### Intrachild Variation

The same general approach to constraints and their ranking can be extended to cases of variable productions *within* a given child's sound system. In instances of intraword variation, where a child produces a given word in different ways, constraints may be organized into strata and then equally, rather than hierarchically, ranked (Demuth, 1997; cf. Tesar & Smolensky, 1998). This allows for a given constraint to be relevant to a given production of a target word. On another occasion, an alternate, coranked constraint on the same stratum may be crucial to that very same word. This then yields different optimal outputs. Similarly, interword variation—when a child produces a target sound in different ways across different contexts or words—has been attributed to the differentiation among lexical categories. When a target sound is produced differently by a child in nouns versus verbs, this has been associated with high-ranking noun faithfulness constraints (Smith, 1997). That is, the segmental and featural structure of the output form of nouns must be faithful to the input; hence, nouns have been observed to be produced more accurately relative to the adult target as opposed to other syntactic categories. Other forms of interword variation in children's productions have been traced to a word's frequency and neighborhood density (Gierut, Morrisette, & Champion, 1999; Levelt & Van de Vijver, 1998). Frequency refers to the number of times a word is used in a language, and density to its number of rhyming word counterparts. Here, the segmental and featural properties of high-frequency words are preserved relative to other low-frequency words in children's outputs. Similarly, properties of words in low-density neighborhoods are also preserved. Taken together, these three examples

related to intrachild variability illustrate OT's potential in accounting for phonological and lexical interactions (see also Grimshaw, 1997).

### Continuity in the Grammar Over Time

A particularly compelling aspect of OT is its ability to account for change in fully developed sound systems over time, while also maintaining continuity in the grammar (Jacobs, 1995). Recall that, within OT, constraints are assumed to be universal. They are present in the grammars of all languages and all speakers at all times. Thus, when a sound system changes, historically or dialectally, constraints are simply reranked.

Extending this to phonological acquisition, those constraints that are present at initial stages of development are also presumed to be the very same constraints present at later points in time. The longitudinal course of developmental change is characterized by reranking constraints. The likelihood is that the markedness constraints in particular will be demoted in children's systems. This follows from the observation that markedness constraints outrank faithfulness constraints in development, which is just the reverse pattern in fully developed systems. With constraint demotion then, violations of lower ranking markedness constraints are no longer fatal, and the grammar of a child becomes more faithful to the input. Notice that this view of change is different from prior derivational accounts involving phonological processes or rules that are lost, suppressed, or eliminated from the grammar over time (Donegan & Stampe, 1979; King, 1969; Kiparsky & Menn, 1977; Stampe, 1973).

To demonstrate how the path of developmental change may be accounted for within an OT framework, we present longitudinal data from Child 24 at two points in time. The phonology of this child has been described in detail elsewhere, with the OT analysis presented here being simplified for ease of exposition (for information about

the child's characteristics, data elicitation, and descriptive analyses, see Barlow, 1997; Barlow & Dinnsen, 1998; Chin & Dinnsen, 1992). Table 1 shows the relevant data to be considered, with samples obtained 3 months apart. At Point 1, key error patterns are cluster reduction and the nonoccurrence of target /s/ across word positions, both of which are common patterns observed in children's outputs. At Point 2, the child produces some clusters, and singleton /s/ occurs target appropriately.

More specifically, the pattern observed at Point 1 involves obstruent + approximant clusters being reduced to a singleton, as for example, in [bo] "blow." Also, singleton /s/ never occurs target appropriately, being realized word initially (in particular) as null, as in [ʌn] "sun." Further, these two error patterns interact in the case of target /s/ + approximant clusters. Notice in Table 1 that for target /s/ + approximant clusters, there is reduction to a singleton, as in [wip] "sweep." Of special interest is the fact that different types of approximant clusters surface in different ways in this child's system: Obstruent + approximant clusters are reduced to the *obstruent*, whereas /s/ + approximant clusters are reduced to the *approximant*. An interaction of error patterns is apparent: Because /s/ does not occur in Child 24's system, /s/ + approximant clusters cannot be reduced to the singleton /s/; rather, these clusters must be reduced to the approximant.

To account for these data at Point 1 in time, four constraints may be posited and ranked, as in (21). These are \*COMPLEX, \*S, MAX, and ONSET. Of these, \*COMPLEX and \*S must be ranked highest. Neither can be violated by a harmonic output in light of the production facts for Child 24. In satisfying these two constraints, certain segments (namely, clusters and /s/) must be absent from this child's output forms. As a result, this requires MAX to be ranked next, to allow for the nonfatal pattern of deletion (in this case, deletion of /s/). ONSET is ranked next to allow for vowel-initial forms such as [ʌn] "sun."

Table 1. Data from Child 24 across two points in time.


Target		Point 1, age 5;0			Point 2, age 5;3			
Obstruent + approximant clusters	"blow"	bo	"blowing"	bowɪn	"blow"	blo	"blowing"	blowɪŋ
	"brother"	bʌrə	"brush"	bʌ	"twin"	twɪn	"climb"	klɪm
	"drum"	dʌm	"dress"	dɛ	"cry"	kwʰar	"glove"	glʌv
Singleton /s/	"sun"	ʌn	"sink"	ɪŋk	"sun"	sʌn	"sink"	sɪŋk
	"dressy"	dɛʔi	"icy"	arʔi	"dressy"	dwɛsi	"icy"	arsi
	"yes"	je	"vase"	veɪ	"yes"	jɛs	"vase"	beɪs
/s/ + approximant clusters	"sweep"	wɪp	"sweeping"	wɪpɪŋ	"sweep"	wɪp	"sweeping"	wɪpɪŋ
	"sleep"	lɪp	"sleeping"	lɪpɪŋ	"sleeping"	lɪpɪŋ		
	"swimming"	wɪmɪŋ			"swimming"	wɪmɪŋ		

(21) Point 1: Relevant constraints and ranking

- \*COMPLEX: Avoid consonant clusters.
- \*S: Avoid /s/.
- MAX: Segments in the input must correspond to segments in the output. (No deletion.)
- ONSET: A syllable must begin with a consonant.
- Ranking: \*COMPLEX, \*S >> MAX >> ONSET

Child 24's constraint ranking at Point 1 in time for each of her distinct substitution patterns is illustrated in (22)–(24). The tableau in (22) shows reduction of obstruent + approximant clusters in the sample word “blow.” In evaluation of the candidates, it is clear that Candidate (a) is most faithful to the input, but is ruled out by its fatal violation of the highly ranked \*COMPLEX constraint because the cluster [bl-] is present in this output form. (Here, \*S is not relevant because there is no /s/ in the target form.) Candidates (b) and (c) are left to compete. Both violate MAX because segments of the input are omitted in these candidates. Candidate (b) violates MAX only once, whereas Candidate (c) violates MAX twice and further incurs an additional violation of lower ranked ONSET. Multiple violations of MAX by Candidate (c) rule this form out, and Candidate (b) is thus found to be the most harmonic by EVAL.<sup>2</sup>


(22) Point 1: /blo/ → [bo]

/blo/ “blow”	*COMPLEX	*S	MAX	ONSET
a. blo	*!			
b.  bo			*	
c. o			**!	*

The tableau in (23) illustrates the impermissibility of /s/ in the sample word “sun.” Two candidates are compared: the faithful Candidate (a), for which all segments from the input are present, and the less faithful Candidate (b), missing /s/ from the input. The same constraints ranked in the same order evaluate this candidate set and determine that Candidate (b) is most harmonic because it does not incur a violation of the highest ranked constraint, \*S. (In this case, \*COMPLEX is not relevant because there is no cluster in the target form.) The winning form does incur a violation of MAX and ONSET, but this is nonfatal because the constraints are lower ranked. Candidate (a) loses outright with its fatal violation of the highly ranked \*S constraint.


<sup>2</sup>Another possible candidate to consider for target “blow” is [lo], which would be chosen as equally optimal by the given constraint ranking. This candidate would be ruled out in favor of [bo] by markedness constraints relevant to sonority sequencing, as in our previous discussion of cluster reduction and the word “swing” (Barlow, 1997; Barlow & Dinnsen, 1998).

(23) Point 1: /sʌn/ → [ʌn]

/sʌn/ “sun”	*COMPLEX	*S	MAX	ONSET
a. sʌn		*!		
b.  ʌn			*	*

The tableau in (24) shows the interaction of cluster reduction with the nonoccurrence of /s/ for the sample item “swim.” In evaluating possible candidate output forms, Candidates (a) and (b) are eliminated outright by violation of the highest ranking constraints. Candidate (a), the most faithful to the input, incurs a violation of both constraints, either of which is fatal, given the presence of the cluster [sw-] and singleton [s]. Candidate (b) incurs a fatal violation of \*S because of the presence of [s] in the output. With these two candidates ruled out, only Candidates (c) and (d) are left to compete as optimal. In cases such as this, the next ranked constraint MAX crucially determines the winning output. Candidate (c) violates MAX once with omission of /s/, whereas Candidate (d) violates MAX twice with omission of both /s/ and /w/. Two violations of MAX by Candidate (d) makes it a less optimal output, being ruled out in favor of the more harmonic Candidate (c). Together, these examples show how the set of four constraints can account for the independent and interacting error patterns observed in Child 24's grammar at Point 1 in time.

(24) Point 1: /swim/ → [wim]

/swim/ “swim”	*COMPLEX	*S	MAX	ONSET
a. swim	*!	*		
b. sim		*!	*	
c.  wim			*	
d. im			**!	*

Turning to the data from Point 2, as in Table 1, it is evident that Child 24's error patterns have changed, with two main improvements taking place. Clusters occur (e.g., [blo] “blow”) and singleton /s/ is produced target appropriately (e.g., [sʌn] “sun”). The interacting error pattern remains, however, such that /s/ + approximant clusters are still reduced to the approximant (e.g., [wim] “swim”). From an OT perspective, the dynamic and static aspects of Child 24's grammar observed at Point 2 require that the same constraints operative at Point 1 be reranked, as in (25).

(25) Point 2: MAX, \*S >> \*COMPLEX >> ONSET

At Point 2, notice that \*COMPLEX must be demoted because consonant clusters are now permitted in Child 24's system. This markedness constraint is ranked lower than MAX to ensure that omission of segments from the

input is not optimal; however, some types of reduction are still tolerated by the grammar. To provide for this, the constraint MAX is equally ranked with \*S to ensure that /s/ will occur correctly, but only in certain circumstances. ONSET remains lowest ranked to allow for vowel-initial words.

As in the tableau in (26), this new ranking allows obstruent + approximant clusters to surface as ambient in words such as “blow.” In this example, Candidate (a) is the most faithful, and also the most harmonic, despite its violation of lower ranked \*COMPLEX. Candidates (b) and (c) are eliminated outright because they fatally violate high-ranking MAX, given segmental mismatches between the input and these two candidate output forms.<sup>3</sup>

(26) Point 2: /blo/ → [blo]

/blo/ “blow”	MAX	*S	*COMPLEX	ONSET
a.  blo			*	
b. bo	*!			
c. o	*!*			*

The revised ranking at Point 2 in time also allows /s/ to occur as in the tableau in (27) for the word “sun.” In this example, Candidate (a) incurs a violation of \*S, and Candidate (b) incurs a violation of MAX. Because these two constraints are equally ranked, neither candidate can be definitively ruled out, and consequently, lower ranked constraints must be consulted by EVAL to determine the harmonic output. Given this, the constraint ONSET (McCarthy & Prince, 1995) singles out Candidate (a) as the winning form because Candidate (b) is in violation, being a more marked vowel-initial form. In this example, notice that /s/ is permissible in the child’s output, even though the constraint \*S is highly ranked. Note that /s/ is considered a rather marked sound relative to other sounds of the target language. In this particular case, however, the target-appropriate Candidate (a) [sʌn] is considered unmarked relative to Candidate (b) [ʌn]. Recall that this present example is a comparison of syllable structure, rather than individual segments. Cross-linguistically, syllables with onsets are considered unmarked relative to onsetless syllables (Blevins, 1995). Consequently, markedness constraints will always favor a syllable that begins with an onset when compared with an onsetless syllable.

<sup>3</sup>Note in (26) that Candidate (c) incurs two violations of MAX and that the violations are formally indicated as \*!\* rather than \*\*! in terms of exclamation point placement. One violation incurred by Candidate (c) is fatal because it is competing with another candidate that does not violate MAX at all—Candidate (a). A second violation of MAX is trivial because Candidate (c) has already been ruled out as a possible harmonic output. Consequently, the exclamation point is placed immediately following the first asterisk (i.e., the fatal violation), not the second.

(27) Point 2: /sʌn/ → [sʌn]


/sʌn/ “sun”	MAX	*S	*COMPLEX	ONSET
a.  sʌn		*		
b. ʌn	*			*!

Importantly, Tableau 27 is revealing of a particular phenomenon within OT known as *emergence of the unmarked* (McCarthy & Prince, 1994, 1995). Emergence of the unmarked arises in such cases as a result of indeterminacy in candidate selection, thereby requiring low-ranked markedness constraints to come into play. For the most part, low-ranked markedness constraints do not affect the harmonic output. In essence, these markedness constraints are so low ranked that their effects are not generally apparent in the output. In instances of emergence of the unmarked, however, lower ranked constraints *do* have consequences for the harmonic output, requiring specifically that unmarked forms surface. Simply stated, emergence of the unmarked is when unmarked forms occur when in fact they should not, given the relative constraint ranking of the grammar. Emergence of the unmarked has been taken as a crucial piece of evidence in verifying the correctness of OT analyses (McCarthy & Prince, 1994, 1995).

Another instance of emergence of the unmarked that derives from the longitudinal reranking of constraints for Child 24 is shown in (28) for the word “swim.” This example demonstrates how the ranking at Point 2 allows for /s/ + approximant clusters to reduce to the singleton approximant, even though both clusters and /s/ are allowed in the system. In evaluation of the candidates relative to the equally, but high-ranking constraints, MAX and \*S, observe that the faithful Candidate (a) incurs one violation of \*S. Similarly, Candidate (c) incurs one violation of MAX. In contrast, Candidates (b) and (d) each incur two violations of these highly ranked constraints. For Candidate (b), both MAX and \*S are violated because the cluster is reduced to [s] in the output. For Candidate (d), two violations of MAX are incurred because two segments of the input /sw-/ are not present in the output. For these reasons, Candidates (b) and (d) are eliminated outright. An indeterminacy thus arises between Candidates (a) and (c) because each has only one violation of the high and equally ranked constraints. The lower ranking constraint \*COMPLEX must therefore be considered by EVAL in determining the winning output. It is apparent that Candidate (a), which includes a consonant cluster, violates \*COMPLEX, whereas Candidate (c) does not. This yields Candidate (c) as the most harmonic output, and emergence of the unmarked is realized once again. That is, consonant clusters are permitted in Child 24’s grammar at Point 2 in

time as a result of demoting \*COMPLEX. Yet this lower ranked markedness constraint still has an effect by preventing certain clusters from surfacing. Consequently, unmarked structure occurs instead in specific output forms, such that singletons, rather than clusters, are produced.

(28) Point 2: /swim/ → [wim]

/swim/ "swim"	MAX	*S	*COMPLEX	ONSET
a. swim		*	*!	
b. sim	*	*!		
c.  wim	*			
d. im	**!			*

The OT analyses of these data from Child 24 have provided a brief explication of how children's error patterns may be described longitudinally and contiguously by constraint reranking. The same four constraints were used, and their relative ranking was sufficient to account for the productive changes that took place over time. In this way, continuity in the grammar was preserved. This sample case had further significance in its demonstration of the concept of emergence of the unmarked. Additional reports of continuity in children's grammars and emergence of the unmarked can be found in Barlow and Dinnsen (1998), Dinnsen and Barlow (1998a), Demuth (1995), Gnanadesikan (1996), and Seidenberg (1997).

## Clinical Applications and Extensions of OT

In the preceding sections, we have illustrated the basic mechanics of OT and have shown that this theoretical framework meets the three basic criteria for a viable theory of phonological acquisition: It captures common error patterns, allows for individual variation, and preserves continuity in the grammar. For the field of speech-language pathology, there is a further question of whether OT may prove to be beneficial in the clinical diagnosis and treatment of children with functional phonological disorders. This question is just beginning to be addressed, but there are some preliminary observations that are worth mentioning.

Consistent with the model of OT, the clinical diagnosis of functional phonological disorders would require that descriptions of children's error patterns be framed as relative rankings of markedness and faithfulness constraints. The universal nature of constraints implies, however, that populations may be unified, such that children's "errors" simply reflect a different grammar which is the result of a unique constraint ranking. If

this premise is accepted, then what may be called for in clinical treatment is a manipulation and reranking of constraints, such that the importance of constraints as assembled in a child's grammar more closely resembles that of the adult phonology. This may mean, for example, that markedness constraints may be demoted in treatment, which will have the consequent effect of the promotion of faithfulness constraints to more closely preserve properties of the input language (cf. Demuth, 1995; Gnanadesikan, 1996; Levelt & Van de Vijver, 1998; Smolensky, 1996b; Tesar & Smolensky, 1998).

There is recent evidence from both perception and production to support, at least in principle, the feasibility of the demotion of markedness constraints. In the perceptual domain, Jusczyk and Smolensky (1997) reported that infants are sensitive to unmarked syllabic structure in the earliest stages of language acquisition, preferring to listen to CV shapes. This changes at later stages, with more marked VC structure taking perceptual preference. These investigators viewed this as evidence that infants have basic internal knowledge of markedness relationships of language. They further interpreted the shifts in perceptual preference as reflective of high-ranking markedness constraints being demoted in development to allow for more marked structures. In the domain of production, Gerken (1996) and Kehoe and Stoel-Gammon (1997) investigated prosodic acquisition by examining stress, syllable structure, and segmental effects in children's early speech. In these studies, it was shown that children's outputs mirror the dominant (unmarked) trochaic pattern of English, with conformity to strong-weak syllables. This too was found to change gradually in development, such that children's productions eventually became faithful to the input, thereby allowing syllabic stress patterns of varied types. As in perception, this was interpreted as a demotion of markedness, with the concurrent advancement of faithfulness constraints over time. These lines of investigation serve to motivate continued study of the effects of constraint manipulation in perceptual and productive domains.

Other production studies directly manipulated presumed markedness and faithfulness constraints in clinical treatment. In one such study, children who presented with phonological delays were taught to produce onset clusters (Gierut, 1999). This aspect of the treatment manipulation was intended to trigger a demotion of markedness constraints so that the children's outputs would become more faithful to the adult grammar, as in their use of complex, in addition to simple, onsets. A further aspect of the treatment manipulation involved varying the kind of cluster that was treated. This was intended as a differential manipulation of presumed faithfulness constraints, as in children's use of certain target clusters to the exclusion of certain others. Results revealed

different patterns and extents of generalization learning following treatment, which appeared to correspond to the presumed ranking of markedness and faithfulness constraints. Specifically, children acquired clusters regardless of experimental assignment, thereby supporting an apparent demotion of the markedness constraint \*COMPLEX. Moreover, children learned clusters to differing degrees depending on the kind of cluster that was taught, thus suggestive of the relative ranking of faithfulness constraints in the grammar. Taken together, these findings reflect a possible reranking of markedness and faithfulness constraints in treatment. Namely, the demotion of a markedness constraint yielded the effect of a differential promotion of faithfulness constraints by experimental condition. In a second study, similar behavioral evidence was obtained following treatment manipulations that involved markedness constraints associated with the phonotactic structure of inventories relative to other faithfulness constraints associated with the lexical properties of treated words (Gierut et al., 1999). These initial (albeit limited) investigations hold promise for experimentally validating the psychological reality of constraints, in general, and for demonstrating the possibility that constraints may be exploited in treatment as a means of inducing change in children's productions, in particular. One obvious question is what precisely triggers constraint reranking. This issue is not unique to acquisition, but applies to OT generally, and is currently being explored (Tesar & Smolensky, 1998).

An additional contribution that OT brings to clinical application is the observation of correlated error patterns in the speech of children with functional phonological disorders. Correlated error patterns of this type have never been noticed using other theoretical models, suggesting that OT may provide new insights into the characterization of phonological disorders. In particular, Dinnsen and Barlow (1998b) noted that manner assimilation co-occurs with liquid gliding. Children who assimilated segments in terms of manner properties also displayed the substitution of unmarked glides for target liquids. Similarly, Stemberger and Bernhardt (1997) reported a co-occurrence involving place assimilation with the establishment of place contrasts. Children who exhibited place assimilation demonstrated a limited number of place distinctions relative to the target phonology. There is a potential clinical implication that derives from these correlated error patterns; namely, the remediation of one pattern may predictably motivate change in the other pattern a fortiori. To illustrate, in the observed manner correlation, children's avoidance of more marked liquids (as reflected by liquid gliding) would be expected to outrank faithfulness to the target English language, which does not assimilate manner features in words. The hypothesis then emerges that demotion of a higher ranked markedness constraint

with treatment will likely result in promotion of a correlated but lower ranked faithfulness constraint *without* treatment. The practicality of this example is that treatment of liquids may be predicted to spontaneously trigger the elimination of other manner assimilations for those children who exhibit such correlated error patterns. This proposal offers intriguing possibilities for treatment efficacy, but it remains to be experimentally tested in a full range of correlated error patterns, using bidirectional treatment targets associated with the various correlated constraints.

Finally, a number of issues in the study of phonological acquisition and disorders have been the focus of renewed debate within the recent OT literature: in particular, the relationship between perception and production (Hale & Reiss, 1998; Seidenberg, 1997; Smolensky, 1996b), the nature of children's representations (Dinnsen & Barlow, 1998a; Gnanadesikan, 1996), and the degree of feature specification required in the representation (Dinnsen, Barlow, & Morrisette, 1997; Itô, Mester, & Padgett, 1995). Definitive answers to these questions have eluded investigators for decades, but OT may bring alternative interpretive perspectives by adding new evidence to complement and extend the available data and views on these topics.

In conclusion, the goal of this tutorial was to introduce OT from a developmental perspective, and to illustrate its potential adequacy as a theory of language acquisition. At this point, it may be premature to advocate OT as the most preferred theory. However, as qualitative and experimental research continue to elaborate and refine the theory, OT may help provide a better understanding of how the process of phonological acquisition may proceed, what the expected range of individual differences is in its course, and how potential deviations in that course may best be modified clinically.

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