The acquisition of consonant feature sequences: Harmony, metathesis and deletion patterns in phonological development

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Dedication

To my loving husband Charles, for supporting me through seemingly interminable years of graduate school, and for being a wonderful father to our two children.

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Abstract

This dissertation examines three processes affecting consonants in child speech: harmony (long-distance assimilation) involving major place features as in *coat* [koʊk]; long-distance metathesis as in *cup* [pʌk]; and initial consonant deletion as in *fish* [ɪs]. These processes are unattested in adult phonology, leading to proposals for child-specific constraints. Initial consonant deletion in particular is a little-understood phenomenon thought to be idiosyncratic. However, my survey of initial consonant deletion as reported in eight languages reveals systematic deletion patterns affecting continuants and sequences of different consonants. I argue that all of these child-specific processes are tied to the acquisition of consonant sequences.

In order to understand the role of these processes in phonological development, I examine consonant acquisition data from a diary study of Grace, an English-acquiring child. I adopt the Bernhardt and Stemberger (1998) variant of Optimality Theory for the analysis since their view of default underspecification, sequences of features, and feature-based approach to sonority permit a unified analysis of harmony, metathesis and initial consonant deletion that explains Grace's trajectory of acquisition as well as the frequency of certain patterns across children.

I show that independently motivated constraints governing feature sequences, onset sonority preferences, initial velars, and the tendency to anticipate features within a prosodic domain explain all of these processes, as well as Grace's onset cluster reduction patterns (e.g. *snake* [seɪk]) and gradual acquisition of different cluster types. Children must learn to produce consonant feature sequences within a word before producing sequences within an onset. Child-specific processes are eliminated as children acquire the speech planning skills necessary to express the contrasts of a mature language, though the constraints remain active in adult phonology.

The longitudinal data provide evidence for both constraint demotion and promotion in learning, as well as distinct roles for two types of faithfulness constraints. One mandates the preservation of non-default features that are specified in the underlying representation, while the other evaluates identity of a correspondent segment to any non-default feature associated with a segment. This distinction permits the derivation of initial consonant deletion as a response to positional constraints on features or feature sequences.

TABLE OF CONTENTS

Index of Tables

1 Introduction

"Children have to be studied individually and longitudinally."

--Macken 1996: 169

1.1 Why consonant harmony, metathesis, and deletion?

In child speech, phonological processes often reflect patterns that are also reported in mature languages. Onset cluster reduction, for example, as in *stop* [tap], is universal in early acquisition, and also occurs in adult phonology, as in Pima plural reduplication [tlam.ba] 'tramp' → [tla.lam.ba] (Riggle 2006). Coda deletion as in *ball* [ba] is similarly prevalent in early acquisition, and is also attested in reduplication in mature languages, as in Korean /sak/ → [sasak] 'crisp' (Davis and Lee 1996). Another common childhood pattern, initial fricative stopping as in *zoo* [du], is reflected in adult phonology in languages such as Spanish, in which the voiced labial stop [b] is limited to initial position while the voiced labial fricative [β] occurs only post-vocalically.[1]

There are several processes reported in child speech, however, that are unattested in fully developed languages. Consonant harmony involving long-distance assimilation of major place features, as in *coat* [koʊk], is prevalent in acquisition (e.g. Vihman 1978), but consonant place harmony in adult languages is limited to minor features, as in harmony affecting sibilants (Rose and Walker 2004, Hansson 2001). Long-distance metathesis of consonant place features as in *cup* [pʌk] is also reported in child speech (Velleman 1996), yet in adult languages, metathesis is generally limited to adjacent segments (Hume 2004). Finally, although less common, initial consonant deletion as in *fish* [ɪs] is attested in early phonological development (e.g. Menn 1971, Smith 1973, Grijzenhout and Joppen-Hellwig 2002) but is non-existent in adult phonology. The lack of comparable processes in adult phonology for these child-specific phenomena has led to various

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[1] This can lead to pronunciations such as *vowels* [bawəlz] by some Spanish learners of English.

proposals for child-specific word templates (Vihman 1976: 220) or constraints (Pater 2002, Grijzenhout and Joppen-Hellwig 2002), the transient emergence of idiosyncratic constraints (Velleman and Vihman 2003), a set of prominence-assigning constraints with a child-specific fixed ranking (Dinnsen and Farris-Trimble 2008), or constraints induced by the child to simplify the output (Becker and Tessier 2010). These proposals leave us without a principled explanation for why these processes occur in child phonology and raise questions for the continuity of constraints in phonological development.

With few exceptions (cf. Velleman 1996 and Brulard and Carr 2003 for harmony and metathesis), these three processes have typically been treated separately and attributed to different rules or constraints. However, the fact that they all involve consonant sequences and are eliminated in the course of phonological development suggests a possibly common etiology. It also begs the question: how does a child proceed from an early system dominated by one or more of these processes to an adult-like grammar in which consonant harmony, long-distance metathesis, and initial consonant deletion have been eliminated?

To investigate the emergence and elimination of harmony, metathesis, and initial consonant deletion, I examine longitudinal data from a diary study of Grace, an English-acquiring child who exhibited all of these processes at some point in her phonological development. While a number of notable diary studies in English acquisition have been published (e.g. Smith 1973, Menn 1976, Macken 1979, Gnanadesikan 2004), Vihman (1996) notes that few case studies give a complete picture of early development, and Bernhardt and Stemberger (1998: 287) suggest that more longitudinal data is needed from many more subjects in order to draw reliable conclusions about developmental stages of early phonological acquisition. The present study complements existing research by providing longitudinal consonant acquisition data from first meaningful utterances at 1;2 (year;month) through age 2;9, when Grace had mastered most target consonants and structures. An advantage of this type of study is that each process can be viewed in the context of the phonological system as a whole, including the consonants the child has acquired and any contextual constraints on their production. Furthermore, the fact that consonant harmony, long-distance metathesis, and initial consonant deletion all occur in her data presents a unique opportunity to understand the specific roles of these three potentially interrelated processes in a child's developing phonology.

With the benefit of a complete picture of her phonological system, it becomes clear that Grace's early consonant harmony, metathesis, and deletion are not completely independent processes, but are all tied to the acquisition of consonant feature sequences. As her phonological development progresses, the effects of the sequence constraints that motivate these child-specific processes are also seen in the cluster reduction patterns associated with her acquisition of onset clusters (e.g. *stop* [tap], *smell* [ɸɛʊ]), which I also analyze in detail. I argue that these processes are gradually eliminated as the child acquires consonant feature sequences, first across a vowel and later for immediately adjacent segments. Furthermore, the specific order of acquisition of sequences determines a particular child's patterns of harmony, metathesis, and initial consonant deletion.

Since Grace's error patterns are in many ways typical, they contribute to a more general understanding of child phonology. Her consonant harmony patterns echo the trends reported across children in previous research in English acquisition as well across languages[2], including tendencies for coronals as undergoers of harmony and for anticipatory assimilation as in *doggie* [gagi]. Long-distance place metathesis occurs exclusively in sequences of dorsal and labial consonants (e.g. *cup* [pʌk]), the most commonly reported metathesis pattern in available studies of English acquisition (Ingram 1974, Compton and Streeter 1977, Jaeger 1997, Brulard and Carr 2003). Initial consonant deletion is the least well studied of these three processes, but I address this gap by undertaking a cross-linguistic survey of available reports of initial consonant deletion in studies of early phonological acquisition.[3] Previously characterized as

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[2] Although the majority of studies reviewed focus on English acquisition, I also discuss available acquisition data from various European languages.

[3] The survey of reports of initial consonant deletion includes data from English, Dutch, German, French, Italian, and Finnish.

atypical (Howell and Dean 1994) and idiosyncratic (Velleman and Vihman 2003), I show that initial consonant deletion is not exceedingly rare and is systematic, tending to affect fricatives and other continuants as well as consonants in target sequences that differ in place and manner. Both types of initial consonant deletion are seen in Grace's data. An understanding of the constraints involved in deriving these patterns in Grace's phonology will lead to a better understanding of initial consonant deletion patterns observed in other children.

The longitudinal data analyzed here bear on several important theoretical issues, including the nature of underlying representations, the nature of faithfulness constraints, and how best to model the learning process in a constraint-based framework. The analysis is couched in the Bernhardt and Stemberger (1998) constraint-based model, a variant of Optimality Theory (OT) oriented toward phonological development that differs in certain respects from standard OT (Prince and Smolensky 2004/1993, McCarthy and Prince 1995). Specifically, Bernhardt and Stemberger (1998) incorporate the role of frequency in deriving underspecified default feature values, posit constraints on feature sequences grounded in the use of cognitive resources in speech planning, propose a constraint formalizing the tendency to anticipate features within a prosodic domain,[4] and define sonority-related constraints based on closed-open cycles of the vocal tract. In addition, they allow learning to be modeled both by demotion of output constraints and promotion of faithfulness constraints. All of these aspects of their model are key to an explanatory and unified analysis of the patterns in the data and how they change over time.

Bernhardt and Stemberger's view of lexical underspecification is uniquely based on the concept of default features, which correspond to the most frequent feature values (where consonants and vowels are treated separately). The most frequent consonant features (e.g. [Coronal], [-sonorant]) surface by default due to low-ranked constraints against these features, and may therefore be underspecified in the lexicon. *Predictable* non-

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[4] Many phonological processes apply within a specific prosodic domain, such as the syllable or stress foot (Steriade 1987a).

default features (such as [+sonorant] for nasals) may also be underspecified, if they can be filled in by co-occurrence constraints. *Contrastive* non-default features, on the other hand, must be specified in the lexicon and are governed by featural preservation constraints. This explains why the non-default, contrastive place features [Labial] and [Dorsal] tend to resist assimilation or deletion and be preserved in the output, either by metathesis or by spreading, especially to underspecified coronal consonants. Combined with the tendency to anticipate features within a prosodic domain, this view also explains the prevalence of anticipatory harmony patterns found both in child phonology (e.g. *duck* [gʌk]) as well as adult harmony systems (e.g. Rwanda /ku-saːz-iːʃ-a/ [guʃaːʒiːʃa] 'cause to grow old').

Sonority-related constraints favoring onset features associated with a closed vocal tract play an important role in determining the susceptibility of certain initial consonants to deletion as well as which member of an onset cluster survives in cluster reduction. Defining these constraints in terms of feature preferences rather than a fixed sonority hierarchy has the advantage of explaining variability across children in order of acquisition of clusters and reduction patterns for /s/-initial clusters, without requiring special treatment of /s/ in the syllabic structure as in previous analyses (e.g. Gierut 1999, Barlow 2001, Jongstra 2003, Goad and Rose 2002, Kwon and Stanford 2006).

My analysis leads me to propose certain innovations to the Bernhardt and Stemberger model. In order to better account for consonant harmony patterns involving bidirectional velar harmony, I introduce a Lingual node into the feature geometry grouping [Coronal] and [Dorsal] features under a common [Lingual][5] feature, which is also useful in explaining certain context-free substitution patterns in child speech and in adult languages. Another minor departure from the Bernhardt and Stemberger model is the reformulation of their constraint preferring [Dorsal] in syllable rimes as a negative constraint prohibiting [Dorsal] in initial position, which is relevant in explaining both metathesis and initial consonant deletion patterns.

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[5] A similar node is suggested in Browman and Goldstein (1989) and briefly discussed in Clements and Hume (1995), although it does not appear in most feature hierarchies.

In addition, I expand their set of constraints on feature sequences to distinguish among three different constraint types relevant in deriving Grace's harmony, metathesis, and deletion patterns. The first constraint type, **Agree(F)** (where F is any feature), is grounded in speech planning considerations and prohibits sequences that differ along a featural parameter such as place or nasality. The second, **NoSequence(F_1…F_2)**, prohibits a specific sequence of feature values, where ordering is crucial. The third, **NotTwice(F)** prohibits the repetition of a feature in a consonant sequence. There are at least two reasons why repetition of a feature might be disfavored. The repetition of a *non-default* consonant feature such as [+continuant] or [+spread glottis] within a prosodic domain (e.g. the syllable or foot) may tax the system more than one occurrence of the feature in question. For immediately adjacent consonants, the repetition of any *manner* feature in sequence will be disfavored due to sonority sequencing preferences. That is, in order to maintain closed-open jaw cycles, sequences of consonants should not share the same aperture manner feature (regardless of default or non-default status).

I also seek an alternative to the derivation of non-minimal repairs suggested in Bernhardt and Stemberger (1998). A non-minimal repair occurs when segmental deletion occurs in response to a constraint on features rather than a change to the offending feature, which would constitute the minimal repair for the constraint in question. Their account relies on a technical difference between deleting and merely delinking features, resulting in floating features that are claimed to survive though unpronounced. In order to avoid this level of abstractness, I rely on a distinction between two types of faithfulness constraints. **Survived(F)** constraints (cf. MAX[F], McCarthy and Prince 1995) are used by Bernhardt and Stemberger (1998) to preserve elements of a segment's underlying representation, including a consonant's root and place nodes and any *contrastive* non-default features. I additionally make use **Identical(F)** constraints (cf. IDENT[F], McCarthy and Prince 1995) to evaluate a substitute segment for identity to the underlying segment's non-default features, including those that are *predictable*. This principled distinction permits featural faithfulness constraints to become decisive in determining whether the costs associated with producing a segment are worth the effort.

My detailed analysis of the concurrent error patterns in Grace's phonology leads me to two somewhat unexpected conclusions. One is that certain features often considered predictable in English must be underlyingly specified in her lexicon and therefore subject to **Survived** constraints. Specifically, I conclude that voiceless fricatives must be specified for both [+continuant] and [+spread glottis] and that glottal /h/ must be specified for [+spread glottis] and [-consonantal]. Another unanticipated conclusion is based on the progression of error patterns in her data over time, which strongly suggests that learning must proceed by both demotion of output constraints and promotion of faithfulness constraints.

The longitudinal data examined here also bear on the continuity of constraints in phonological development. I conclude that far from being idiosyncratic or limited to child phonology, all of the constraints responsible for these early processes are independently motivated and have observable effects in adult phonology as well. The fact that they do not produce the same type of long-distance assimilation, metathesis, and deletion in mature languages is seen as a by-product of the child's need to be faithful to the complex featural sequences required to express the range of lexical contrasts demanded by a fully developed language. The analysis advocated here obviates the need to propose idiosyncratic or child-specific constraints or fixed rankings.

I begin by presenting the methods of the study and an overview of Grace's data. In Chapter 2, I cover theoretical preliminaries and the unique aspects of the Bernhardt and Stemberger (1998) model that are crucial for the analysis. This is followed in Chapter 3 by an overview of consonant harmony and long-distance metathesis in phonological development and a unified analysis of Grace's harmony and metathesis patterns. In Chapter 4, I discuss how the model explains common harmony and metathesis patterns observed in other children. Chapter 5 addresses Grace's early initial consonant deletion patterns, showing how one type of deletion results from constraints on feature sequences, while another is caused by sonority-related constraints on onset features. Finally, Chapter 6 presents a detailed analysis of Grace's onset cluster reduction patterns, attributing them to many of the same constraints responsible for her initial consonant deletion patterns. I conclude that a small set of independently motivated constraints drive all of these early processes. The development of better speech planning skills and drive for increasing faithfulness to the consonant sequences of the adult language lead to the elimination of consonant harmony of major place features, long-distance metathesis, and initial consonant deletion, yet the constraints themselves remain active in adult phonologies in cluster reduction, local assimilation and metathesis, and in consonant harmony systems affecting minor place features.

1.2 Methods: a longitudinal case study in consonant acquisition

The primary data for analysis come from a diary study of my daughter Grace, an English-acquiring child, beginning with her first words at age 1;1.[6] The data collection methods were similar to other published studies of early phonological acquisition (e.g. Smith 1973, Berg 1992). To the extent possible, throughout Grace's first year of meaningful speech production, I transcribed each new form heard in her spontaneous speech, including new vocabulary words as well as novel pronunciations of existing words. The majority of data transcription occurred during the one-word stage of acquisition, when she produced primarily single-word utterances. By age two, however, Grace's vocabulary had grown to over 300 words and she was using two-word utterances on a fairly regular basis. At this point, daily transcription of new utterances ceased and only selected words were transcribed from age 2;0 to 2;9, in particular those related to onset cluster acquisition.

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[6] Grace was adopted from Korea at the age of five months, but there is reason to believe her early Korean language input had little influence on her subsequent phonological development. Studies have shown that nine-month-olds prefer utterances respecting the sound patterns of their language input, but six-month-olds do not (Jusczyk et al. 1993, Jusczyk et al. 1994). Grace's exposure to Korean was further limited by a premature birth (at 31 weeks) that resulted in hospitalization for her first month. Otherwise, Grace was a healthy child with no developmental delays, exhibiting above average intelligence (98th percentile) at the age of four.

Although her speech was not recorded, each transcription was typically based on multiple tokens to verify both the phonetic form and the referent, particularly when her pronunciation was far removed from the adult target (e.g. [mai] for *bunny*). An obvious drawback to this type of diary study is that the transcriptions cannot be independently verified through audio playback. However, this methodology is consistent with a number of diary studies in the literature (e.g. Smith 1973, Donahue 1986, Brulard and Carr 2003; see Inkelas and Rose 2007 for discussion). An advantage of this approach is the level of knowledge the researcher has of the child's phonology due to familiarity and prolonged contact with the subject.

A limitation of the study is that although transcriptions were made on a daily basis, the specific date of any given utterance was not tracked. Instead, transcriptions were listed in chronological order and tracked by month, thereby indicating whether they were acquired toward the beginning or the end of the month in question. A further limitation is that changes in pronunciation were not noted for all existing vocabulary words; for example, I failed to note the date at which velar harmony in *cut* ceased and the sequence was first produced faithfully. However, her acquisition of similar sequences (e.g. *cat*) at 1;8 leads me to believe that *cut* began to be produced accurately at the same time. In some cases, the lack of precision in the dating of transcriptions prevents me from drawing conclusions regarding the complete state of Grace's phonology at a given point in time. The analysis presented here attempts to account for all known aspects of her phonology, noting areas of uncertainty as appropriate.

The present study focuses on relatively salient features such as consonant manner and major consonant place of articulation, whose transcription I deem reliable. When available, visual information was used to confirm place of articulation, in particular for production of the voiceless bilabial fricative [ɸ]. The transcriptions represent my best estimation of vowel quality, but I do not make any claims regarding the acquisition of particular vowel features. My greater confidence in the accuracy of the consonant transcriptions is consistent with the greater reliability of consonant transcription in studies of infant vocalizations (e.g. Davis and MacNeilage 1995). Stress was not marked, though in general, stress patterns were similar to adult targets.[7] Transcription of voicing in stops was broad and does not reflect aspiration or small changes in VOT (voice onset time). However, I noted that in her early phonology, voiceless stops were unaspirated and word-final obstruents were consistently devoiced. Claims regarding voicing do not form a central part of my analysis and are used only to illustrate the promotion of faithfulness constraints (see 2.2.6).

A potential pitfall in diary studies discussed in Vihman (1978) is the risk of observer bias; that is, the linguist parent may tend to transcribe all of the phonologically interesting forms, while neglecting the rather uninteresting forms pronounced according to the adult target. However, since a primary initial goal of the study was to track the growth of Grace's vocabulary, each new word was transcribed, regardless of how "uninteresting" it may have been. This practice remained in effect until about age two, after harmony, metathesis, and deletion had been eliminated. By this time, advances in her phonology were largely limited to the acquisition of clusters and liquids. Subsequently, the quantity of utterances made it no longer practical to continue transcribing all new words, and it was indeed the more interesting phonological forms that were transcribed.

Although Grace acquired English in an English-speaking environment, a unique aspect of her language acquisition is that a primary caregiver spoke to her in French on a regular basis. However, given the preponderance of English speakers in her life, English was the dominant language in her acquisition. Less than 10% of Grace's productive vocabulary over the period of the study consisted of French words, and therefore most of the data cited is in English. On rare occasions when French data is cited in this paper, it will be brought to the reader's attention, e.g. /pɛɲ/ → [mɛn] (*Fr.* 'comb').

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[7] For the first few months, there was little perceivable difference in stress cues between syllables in disyllabic words, consistent with previous findings on stress in early English acquisition (Schwartz and Goffman 1995: 886; Pollock et al. 1993).

While some researchers report a fair amount of variation in a child's pronunciations of a given word (e.g. Macken 1978, Macken 1979, Vihman and Velleman 1989), Grace's pronunciations of lexical items at any given point in time were generally quite stable. In only a few instances, a variant pronunciation was noted along with the dominant pronunciation. Changes in her phonology were quite abrupt, with new abilities transferring to applicable lexical items in the space of a day or two with very few exceptions.[8] Similarly abrupt and systematic changes in substitution patterns are observed in other studies as well (Levelt and van Oostendorp 2007, Smith 1973). I do not specifically address variation in this study, except to note that for a short time, newly acquired segments, sequences, or structures may co-exist with old forms. This may be due to different demands in language production (e.g. syntax and phonology) competing for limited cognitive resources, causing one aspect of production to suffer (see Howell and Dean 1994: 8; Bernhardt and Stemberger 1998; McCune and Vihman 2001). In a constraint-based model, this can be reflected in temporarily unstable rankings of constraints.[9]

It has been suggested that a child's early phonology is pre-systematic (Vihman and Velleman 1989: 149) and does not become systematic until productive vocabulary size reaches 25-100 words, i.e. around 18 months of age (Velleman 1998: 5). However, there are certain generalizations that hold true of Grace's earliest utterances. Up until age 1;6, all of her words are limited to one consonant place and manner of articulation, a restriction that leads to strategies of avoidance, deletion and consonant harmony. In this way, systematicity is present from the onset of meaningful speech. With this in mind, I present an overview of Grace's data beginning with her first words at 1;1.

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[8] One exception is the apparent fossilization of an early pronunciation of *milk* as [nɛʊk], which persisted long after she had acquired similar consonant sequences in words such as *book* and *monkey*. Velleman (1998) terms such pronunciations "phonological idioms," citing a similar example of a child whose first words included her name *Mickey* as [didi], a pronunciation that persisted even after she had acquired the same sequence in *monkey*.

[9] Other OT accounts of variation include the ranking of conflicting constraints within a single stratum (Anttila 1997, Pater and Werle 2001), the Gradual Constraint-Ranking Algorithm (Boersma 1998, chs. 14-15; Boersma and Levelt 2000), and Error Selective Learning, in which the grammar competes with stored production forms that decay over time (Tessier 2009).

1.3 Overview of Grace's data, age 1;1-2;9

A brief overview of Grace's development is provided below with representative examples of her various consonant deletion and substitution patterns (see Appendix A for complete data transcribed). For ease of exposition, I present her data in four stages that correspond to important advances in her phonology.[10]

1.3.1 Age 1;1-1;6: First words (vocabulary < 50)

In her earliest stage of language production Grace has a very limited productive speech capacity. Her consonantal inventory is largely limited to oral and nasal stops, although a few coronal fricatives appear in word-final position.[11] She produces no liquids or glides. Word-initial [h] appears only in *hi* and *hello*. Words are very simple in syllabic structure, limited to CV, CVCV, or CVC form. The most striking characteristic of her early words is that they are limited to only one consonantal place and manner within the word. This is sometimes achieved through vocabulary selection, as in 1(a); sometimes via deletion as in 1(b); and somewhat later through consonant harmony as in 1(c). Some deletion of codas and initial unstressed syllables is attested, which is unsurprising given universal preferences for open syllables and trochaic stress preferences in English. Initial consonant deletion also occurs somewhat unexpectedly for certain target sequences. Examples of early words containing only one consonantal place of articulation are listed in (1), with the age of first utterance indicated in parentheses.

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[10] The stages presented here are based on an arbitrary choice of advances in her phonology and I make no claims regarding their theoretical importance.

[11] Grace's early nasal production included one idiosyncracy from age 1;1-1;5, when /m/ was produced as a labio-lingual nasal (occurring only in the word *Mama*).

(1) Initial stage: one consonantal place and manner per word (1;1-1;6)

a) Achieved by vocabulary selection

Daddy [dæi] (1;1)
cracker [kækʊ] *go* [goʊ] *hi* [haɪ] (1;3)
"boop" [bʊp] (1;4) *cookie* [kʊk:i] (1;5)
baby [bibi] Fr. /pɔm/ [mɔm] 'apple' (1;6)

b) Achieved by deletion

bread [bɛ] *bottle* [ba] (1;2) *boat* [boʊ]
book [oʊk] (1;5) *juice* [ʊs] *hat* [æt]
please [is] (1;6) *banana* [nænæ][12]

c) Achieved by consonant harmony (age 1;6)

coat [kɔk] *cut* [kʌk] *boat* [boʊp]

1.3.2 Age 1;7-1;8: Vocabulary spurt to > 170 words

A spurt in vocabulary growth is often observed around 18 months of age (Bates et al. 1994, Fee 1995), and Grace is typical in this regard. Her vocabulary spurt just as she reaches 1;7 coincides with her new-found ability to produce consonant sequences of different place and manner within a word, eliminating initial /h/ deletion in *hat*. With regard to place feature sequences, labial-initial sequences are now possible, eliminating labial harmony in *boat* and initial labial deletion in *book* as shown in (2).

(2) Vocabulary spurt with acquisition of labial-initial sequences (age 1;7-1;8)

book [boʊk] *splash* [pas] *broccoli* [baki] *bug* [bʌk]
bike [baɪk] *monkey* [mʌki] *boat* [boʊt]
Fr. /tɔmat/ [mat] 'tomato' Fr. /pat/ [pat] 'pasta'

Glottal /h/ combines freely in sequence with any other place of articulation (e.g. *hot* [hat]), *hop* [hap]), but consonant place sequences continue to be restricted. While labial-

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[12] This is an example of initial unstressed syllable deletion, which is common in English acquisition due to trochaic stress preferences and the low salience of unstressed syllables (see Kehoe 1999). This type of deletion persists throughout Grace's first year of speech (e.g. *again* [gɛn] at 1;8; *surprise* [paɪs], *enough* [nʌɸ], *giraffe* [jæɸ], *raccoon* [ku:n] at 1;9; *guitar* [ta:] at 1;10).

initial sequences are possible, labial-final sequences are not, leading to occasional metathesis of target velar + labial sequences (e.g. *cup* [pʌk]). Coronals continue to undergo velar harmony until age 1;8 (halfway through the month), though initial coronal stops are sometimes deleted.

(3) Metathesis and harmony patterns, age 1;7-1;8

a) Metathesis of velar + labial sequences

grape [beɪk] (1;7) *cup* [pʌk] ~ [pʌp] (1;8)

b) Persistent velar harmony and initial coronal deletion

truck [kʌk] *cold* [koʊk] *duck* [ʌk]

Initial fricatives and glides are still not possible and undergo deletion or [h] substitution. Liquids are still absent and also subject to deletion word-initially.

(4) Initial consonant deletion and glottal substitution, age 1;7-1;8

a) Deletion of initial consonants

shoes [us] *woof* [ʊɸ] *rain* [eɪn] *luke* [uk]

b) [h] substitution of initial continuants

walk [hak] *rock* [hak] *sock* [hak] *wipe* [haɪp]

All target onset clusters during this stage are reduced to the stop, as in *brush* [bʌs], *sky* [kaɪ] and *snap* [næp].

1.3.3 Age 1;8-1;11: Expanding abilities (> 300 words)

About two weeks before reaching 1;9, Grace acquires the ability to produce sequences of differing lingual articulations, e.g. coronal followed by dorsal, thus eliminating velar harmony and initial coronal deletion. She also begins producing velar-initial sequences, thereby eliminating metathesis, yet anticipatory harmony persists in words with target affricates as illustrated in (5).

(5) Lingual sequence production (1;8-1;11)

duck [dʌk] *cat* [kæt] BUT: *chicken* [kɪkɛn] *kitchen* [tɕɪtɕən]

Grace acquires word-initial fricatives and the palatal glide /j/ at 1;9. Shortly thereafter, she changes her onset cluster reduction strategy for /s/+ nasal stop clusters only. Instead of retaining the nasal, she now preserves the fricative as in *snap* [sæp]. In the case of target /sm/ onset clusters, coalescence occurs, preserving the labial place of articulation as in *smell* [ɸɛʊ].[13] Acquisition of initial /w/ is delayed until 1;11.

(6) Acquisition of initial continuants

a) Word-initial fricatives and /j/ (1;9)

see [siː]   *flute* [ɸut]   *snack* [sæk]   *smell* [ɸɛʊ]

yucky [jʌki]   *yummy* [jʌmi]   *wipe* [jaɪp]   *rice* [jaɪs]

b) Acquisition of initial /w/ (1;11)

wipe [waɪp]   *leg* [weɪk]

By the time she turns two, Grace has acquired approximately 300 words, a typical vocabulary size for a 24-month-old (Smith et al. 2006). As mentioned above, her vocabulary growth at this age made continuing transcription of all new words impractical; however, I continued to transcribe words related to persistent difficulties with consonant acquisition, especially concerning onset clusters.

1.3.4 Age 1;11-2;9: Onset cluster acquisition

Grace's acquisition of /w/ at 1;11 leads to production of her first onset clusters, consisting of obstruent + [w] as in (7).

(7) First onset clusters: obstruent + glide

Grace [gweɪs]   *sleep* [swip]

However, other clusters continue to undergo reduction. In /s/+oral stop clusters, the fricative deletes, while in /s/+nasal clusters, the nasal deletes, as seen in (8). As mentioned above, coalescence of fricative manner and labial place occurs in /sm/ target onset clusters.

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[13] At this age, bilabial fricatives regularly substituted for both labiodental and interdental fricatives. Production of bilabial fricatives before labiodentals is reported in several other English-acquiring children (Bernhardt and Stemberger 1998: 301). Grace does not acquire labiodental fricatives until 2;10.

(8) Cluster reduction patterns for /s/-initial clusters (1;11-2;4)

a) /s/ + stop clusters

spill [pɪʊ] *stuck* [tʌk] *scratch* [kwætʃ]

b) /s/ + nasal clusters

snap [sæp] *smooth* [ɸuβ].

At 2;4, she acquires /s/+oral stop clusters, correcting her pronunciations of *spill* [spɪʊ] and *stuck* [stʌk]. This leads almost immediately to production of three-member clusters (e.g. *stripe* [stwaɪp]), in which she successfully combines the consonant sequences she has already acquired. Finally, /s/+nasal is the last cluster type to be acquired, with successful productions of the clusters in *snack* [snæk] and *smell* [smɛʊ] at age 2;9.

Thus while Grace's acquisition of consonants proceeds gradually, she moves quickly through a variety of strategies to deal with her production limitations, including lexical selection, labial and velar harmony, occasional long-distance metathesis of velars and labials, and deletion of initial consonants as well as one or more members of a complex onset. This brief overview of her phonological development suggests that the gradual acquisition of consonant sequences, first across a vowel and later within complex onsets, plays an important role in motivating these processes. Before proceeding to a formal analysis of her longitudinal data, I discuss some theoretical preliminaries, particularly concerning the theoretical framework I have chosen, the constraint-based model of Bernhardt and Stemberger (1998).

2 Theoretical background and framework

"Like any theory, a constraint-based view is valuable only insofar as it provides us with useful insights about behavior."

--Bernhardt and Stemberger 1998: 151

In the analysis to follow, I adopt a slightly modified version of the Bernhardt and Stemberger (1998) variant of Optimality Theory (OT), which differs in certain respects from classic OT (Prince and Smolensky 1993/2004, McCarthy and Prince 1995). While no phonological model is a perfect representation of actual human behavior, I find that the Bernhardt and Stemberger (1998) variant of OT provides the most insightful framework for understanding Grace's data as well as patterns across children, due to their view of default underspecification based on frequency; a comprehensive set of constraints governing feature sequences; and feature-based onset sonority constraints grounded in closed-open cycles of the vocal tract. In this chapter, I discuss theoretical assumptions key to my analysis and present the set of relevant constraints to be used.

2.1 The nature of underlying representations

2.1.1 Underlying representations and default underspecification

Although it is not universally agreed that the child's mental lexicon contains accurate underlying representations of the adult input,[14] I follow many researchers in child phonology in assuming that with few exceptions, by the onset of meaningful speech, a child with normal hearing perceives the adult forms quite accurately and stores the phonological features of each word in the mental lexicon (e.g. Smith 1973, Macken 1996, Jaeger 1997, Bernhardt and Stemberger 1998, inter alia). Positing an adult-like acoustic-

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[14] Vihman (1981), for example, suggests that children's early words may be stored as incompletely specified underlying forms based on the word shape as a whole. See also Vihman (1996) and Fikkert and Levelt (2008) for the view that the lexicon in early stages consists of holistic representations that are not yet segmentalized.

perceptual representation is the simplest assumption we can make, given the evidence (Redford and Miikkulainen 2007).

There is a variety of evidence pointing to generally accurate underlying representations of lexical items, even in very young children. The so-called "fis" phenomenon illustrates this, named after an example in which a child produced *fish* as [fɪs] but did not accept an adult's imitation of the error as a correct pronunciation (Berko and Brown 1960). Similarly, a French child who said "tosson" for both *garçon* 'boy' and *cochon* 'pig' objected when someone else called a boy a *cochon* or a pig a *garçon* (Jakobson 1968: 22). Dodd (1975) found that children were better at understanding adult pronunciations of words than they were at understanding their own or other children's imperfect speech, indicating that underlying representations of lexical items were based on accurate perception of the adult forms, not their own deviant phonological forms.

It has also been widely demonstrated that young children correctly perceive consonantal contrasts that they cannot yet produce accurately. A study of 14 children aged 1;10 to 2;2 succeeded on minimal pair discrimination tasks for many phonological contrasts, including those they could not yet produce (Eilers and Oller 1976).[15] A study of 60 children aged 1;2 to 1;10 testing their ability to recognize correct and incorrect pronunciations of familiar words concluded that they were accurately encoding consonant features even in words they could not yet produce (Swingley 2009). Ringo (1985) and Smith (1973) both indicate that their subjects successfully discriminated contrasts that they could not yet produce. Smith (1973) points out that when Amahl acquired the ability to produce onset clusters, they appeared only in words with underlying clusters and not in all forms previously neutralized to the same onset (e.g. *bed* and *bread*), indicating that the underlying forms were correctly stored. Children's

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[15] An exception was the perceptual distinction between [f] and [θ] (i.e. [fɪʃ] v. [θɪʃ]), which none of the children successfully demonstrated. The similar formant structure and intensity of these fricatives contributes to their perceptual confusion (Velleman 1988, cited in Bernhardt and Stemberger 1998: 13; additional references cited in Locke 1983: 147). This is no doubt a factor in the frequency of [f] for /θ/ substitutions in some English dialects, especially in codas (e.g. *birthday* [bəɹfdeɪ]).

ability to perceive and encode distinctive features prior to production is also supported by a perception study showing that infants prefer familiar words over unfamiliar words, but not when onset or coda segments are mispronounced by a single feature (Swingley 2009). Studies of children with functional phonological delays have also concluded that they perceive adult forms accurately and form their underlying representations accordingly (Brett, Chiat, and Pilcher 1987; Storkel 2004).

Gnanadesikan (1995/2004) presents additional convincing evidence that the child's underlying form is featurally accurate despite significant discrepancies in the output. For example, although her subject consistently substituted initial unstressed syllables with the dummy syllable [fi], initial place of articulation was nevertheless preserved in the stressed syllable, as in *koala* [fi.ka.la] and *police* [fi.pis]. Similar examples of labial preservation despite initial syllable deletion include *banana* as [bani] (Kehoe 1999: 40), Dutch *banaan* [maːn] (Fikkert 1994: 19), and Spanish *manzana* [mana] 'apple' and *Fernando* [mano] (Macken 1992).

Assuming adult-like perception and underlying representations, there remains the question of which features are stored in the mental lexicon. I assume a standard set of phonological features defined along articulatory dimensions (see definitions in Appendix A). It has been widely argued that only contrastive phonological features are specified in the underlying representation of a word, while predictable features are filled in by rules or constraints (e.g. Steriade 1987b, Mester and Itô 1989, Avery and Rice 1989, Brown and Matthews 1997). For example, if voicing is not contrastive for obstruents in a language, [-voice] need not be specified in the lexicon, as all obstruents will be predictably voiceless. Radical underspecification (Archangeli 1988, Pulleyblank 1988) goes a step further, claiming that only one value of all binary features need be specified, since the other will appear by default if not specified. For example, although obstruent voicing is contrastive in English, it can be argued that only [+voice] need be specified, since [-voice] default or unmarked value, as seen in the fact that many languages have only voiceless obtruents, and all languages with voiced obstruents also allow voiceless obstruents. Given a rule filling in [-voice] as the default or a constraint against the co-occurrence of [-sonorant] and [+voice], voicing will only surface where it is called for by an underlying [+voice] specification. A similar approach is to claim that [voice] is a privative feature that is either present or absent, in which case no featural specification would be necessary for a voiceless segment (e.g. Ito and Mester 1989, Lombardi 2001).

Default underspecification is a slightly different alternative advocated by Bernhardt and Stemberger (1998). This approach is based on the concept that default feature values correspond to the most frequent feature values, and arise during the babbling period based on input from the adult language.[16] Due to their frequency, these features require the fewest cognitive resources to access, facilitating their production (Bernhardt and Stemberger 1998: 230). For most normally developing children, for example, the most frequent consonant features are [Coronal] for place, [-continuant] for oral aperture and [-nasal] for nasality, values that also correspond to the consonant features most commonly found cross-linguistically (those typically considered to be "unmarked").

I surmise that articulatory considerations may contribute to the frequency of certain features in human language, leading to their default status in most languages and children. For consonants, for example, [-continuant] is a natural default the complete closure involved in stop articulations is a ballistic movement that does not require fine motor control (Kent 1992). The fact that humans have a greater degree of muscular control and feedback receptors on the tip of the tongue than the tongue body (Drachman 1973b) permits a wider variety of possible coronal articulations than other places of articulation, contributing to the frequency of coronals in the world's languages (Keating 1991). The frequency of coronals in the input the child receives in turn leads to the derivation of [Coronal] as the default place feature.[17]

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[16] It is not clear whether type or token frequency is most important, and Bernhardt and Stemberger (1998) leave this as an open question. Bybee (2001) and Pierrehumbert (2003) suggest that generalizations are made over token frequency, while Richtsmeier et al. (2009) present experimental evidence suggesting that type frequency aids phonotactic learning.

[17] An interesting effect of the frequency of coronals in the input is that in discrimination tasks for place of articulation, children are more likely to make errors in the direction of coronals, such that coronals are correctly perceived as coronals more often than labials are perceived as labials or

This is a somewhat different from the common view that [Coronal] is the universally unmarked place of articulation (see papers in Paradis and Prunet 1991). While articulatory factors lead to the emergence of [Coronal] as the default place feature in most languages, these can be overridden by frequency considerations in a given language. For example, Beckman, et al. (2003) argue that the high frequency of velar stops in Japanese may lead to [Dorsal] as the default place of articulation, based on evidence that children substitute velars more often for coronals than the reverse (but cf. Ueda 1996 for evidence of velar fronting in Japanese-acquiring children). Based on evidence from asymmetrical assimilation patterns, Hume and Tserdanalis (2002) make a convincing case for [Labial] as the unmarked place feature in Sri Lankan Portuguese Creole, which they claim is directly correlated to the fact that it is the most frequent place feature (see also Hume 2004 for discussion of the role of frequency in the predictability of features).

Additional evidence to support frequency as the primary factor in determining the default feature value comes from a comparison of developmental studies in hearing and deaf infants acquiring English (Davis and MacNeilage 2002). Nasal consonants predominate in hearing-impaired infants, while infants with normal hearing produce about 75-80% oral consonants, despite the fact that an active muscle contraction is required for suppression of nasality. The higher proportion of oral consonants in hearing children corresponds to the higher frequency of oral consonants in the adult language they are exposed to, where they permit a broader range of salient manner and place contrasts. A study of babbling patterns in four Swedish-acquiring children seems to lend additional support to the view that the phonetic inventory is influenced by exposure to the frequency properties of the adult input, since infants produced a higher frequency of nasals in early productions (prior to about 9 months of age) before non-nasal segments began to predominate (Roug et al. 1989).

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dorsals as dorsals (Brown and Matthews 1997). (That is, when in doubt about place of articulation, children guess the most likely place feature based on frequency.)

Default feature values are thus the most frequent features, and as such are easily activated for production in the system (Bernhardt and Stemberger 1998: 271). These are therefore the features that will surface in the absence of any other feature specification. High-frequency elements are selected in the system by default unless lower-frequency competitors are sufficiently activated. As a result, it is assumed that default features are underspecified in the lexicon. For consonants, the default feature values for English (and many other languages) are listed in (9), based on /t/ being maximally underspecified.[18]

(9) Typical default feature values for consonants
Place: Coronal, +anterior
Manner: +consonantal, -sonorant, -continuant, -nasal, -lateral
Laryngeal: -voiced, –spread glottis, -constricted glottis

Underspecification of these feature values based on frequency has the advantage of explaining both why they appear in epenthetic environments and why they tend to undergo assimilation. For an epenthetic consonant, where only the presence of consonantal material is required, the most frequent features will surface since they are most easily accessible. At the same time, the underspecification of these features in underlying consonants makes these features susceptible to assimilation by the spreading of an underlyingly specified place feature from a nearby consonant, as occurs in some dialects in the phrase *could be* [kʊb bi], where a coronal stop assimilates in place to a following stop. Default features are susceptible to replacement by assimilation, while non-default features are prone to spreading.

Default underspecification resembles radical underspecification in that only one value of a feature need be specified. Only non-default features may be specified, but a distinction is made between contrastive and predictable (or redundant) non-default features. *Contrastive* non-default features must be specified in the lexicon in order to appear in the output (e.g. [Labial] and [Dorsal] place, [+continuant] and voicing for

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[18] While /t/ is specified for a Place node (unlike glottals, which lack a Place node), the specific place feature is left unspecified.

obstruents, [+nasal], etc.). *Predictable* non-default features, on the other hand, need not be specified if other constraints are ranked highly enough. For example, [+voice] is considered to be a non-default feature for consonants, but voicing is predictable for sonorants. If a highly ranked co-occurrence constraint promotes voicing in sonorants, then voicing need not be specified underlyingly in order for a voiced sonorant to surface. As observed by Dresher (2009: 98), "[w]e can explain why rules spreading voicing values do not affect sonorants, and are not triggered by sonorants, if sonorants indeed lack contrastive specifications for [voiced]."

However, Bernhardt and Stemberger (1998) suggest that predictable non-default features may be specified in the lexicon, if relevant co-occurrence constraints are not ranked high enough. They note that some acquisition data is best explained by the specification of an apparently predictable non-default feature. An example comes from the reduction of fricative-sonorant English clusters to voiceless sonorants in Amahl's phonological development (Smith 1973), given in (10).

(10) Voiceless sonorant production in cluster reduction (Amahl, Smith 1973)

Smith [m̥ɪs] *sneeze* [n̥id] *slug* [ɬʌg]

This is somewhat unexpected, since sonorants are predictably voiced in English and voiceless fricatives are predictably [+spread glottis]. We expect the sonorant to surface as voiced without any influence from the deleted voiceless fricative. Bernhardt and Stemberger suggest that voiceless sonorants in these cases result from preservation of the non-default feature [+s.g.] associated with the voiceless fricative, suggesting that it is specified underlyingly even though it is predictable (1998: 397). Although Grace never exhibited this particular error pattern, I conclude that [+s.g.] must have been similarly specified in her grammar for voiceless fricatives, based on a detailed analysis of her initial consonant deletion and cluster reduction patterns (see 5.2.3).

Based on the evidence for the role of frequency and default feature values in the phonology, I adopt default underspecification for the present analysis. The implications of this approach for constraint rankings will be addressed below in 2.2.2 and 2.2.5.

Before defining the relevant constraints for my data analysis, I discuss the role of feature geometry in underlying representations and propose a slight modification to the hierarchy assumed in Bernhardt and Stemberger (1998).

2.1.2 Feature geometry and addition of Lingual node

While some have argued that feature geometry is unnecessary or redundant within an OT framework (e.g. Padgett 1995, 2002, Yip 2004), I follow Bernhardt and Stemberger (1998) in the view that it is useful to conceive of features as being organized into a hierarchy that follows from the organization of the vocal tract and from cross-linguistic assimilation patterns. For example, the assumption that consonants occupy their own tier in the hierarchy, based on phonological processes involving consonants but not intervening vowels (McCarthy 1981, Archangeli 1985), is crucial for the constraints on sequences of consonant features used in the present analysis of harmony and non-local metathesis. The consonant-vowel distinction for place features is typically reflected in the use of separate C-Place and V-Place nodes (e.g. Clements and Hume 1995, Zoll 1998, Bernhardt and Stemberger 1998). This view can explain why glides, which are considered to have vocalic place features, may be transparent to consonant place harmony (e.g. Macken 1979, Donahue 1986). If a phonological process or constraint holds only over C-Place features, intervening V-Place features may not be affected. However, there is also evidence for assimilation of features such as labiality or backness between consonants and vowels. This is not uncommon in child phonology (see Bernhardt and Stemberger 1998: 560; Pater and Werle 2003; Fikkert and Levelt 2008). For example, a child who normally fronts velars may realize them correctly in the context of a following back vowel (Howell and Dean 1994: 35). Similar consonant-vowel interactions can also occur in adult phonology, such as when a consonant's place feature determines epenthetic vowel quality, most commonly involving insertion of a rounded vowel after a labial consonant (Uffmann 2006). This suggests uniformity of major place feature nodes for both consonants and vowels. Following Bernhardt and Stemberger (1998: 97) I assume a generic Place node dominating C-Place and V-Place nodes, as illustrated in (11).

(11) Consonant and vowel place feature geometry

```
                         Place
                      /         \
              C-Place             V-Place[19]
             /   |    \           /   |   \
        Labial Coronal Dorsal   Labial Coronal Dorsal
                      / | \                  / | \
                  [hi] [lo] [bk]         [hi] [lo] [bk]
```

As shown above, standard feature hierarchies (e.g. Sagey 1986, Clements and Hume 1995, Bernhardt and Stemberger 1998) link the major consonant place features directly to the Place node. I propose a minor revision in the organization of place features that is a natural extension of an articulator-based feature theory: the addition of a Lingual place node as shown in (12). Such a node is not a new concept, having been recognized as a structural constituent in previous models (e.g. Anderson and Ewen 1987, Brown and Matthews 1997). A similar node, the Tongue node, is suggested in Browman and Goldstein's (1989) articulator-based feature model. Clements and Hume (1995) discuss the fact that a lingual node would more easily capture certain phonological patterns, such as processes in Mandarin Chinese and Slovak that apply to lingual but not labial consonants and the spreading of both coronal and dorsal features in Turkish vowel harmony. In the present model, the Lingual node is simply meant to reflect the fact that both [Coronal] and [Dorsal] articulations are made with the tongue and are therefore lingual articulations.

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[19] All vowels are assumed to have a [Dorsal] feature node specified for [back], [high], and [low]. Rounded vowels and glides additionally have a [Labial] feature, and front vowels and glides additionally have a [Coronal] feature.

(12) Proposed revision to feature geometry: Lingual node

```
              Place
             /     \
       Labial    Lingual
                   / \
             Coronal  Dorsal
```

As far back as Jakobson and Halle (1956), it has been observed that the first place contrast to be established in phonological development is the contrast between labial and coronal consonants, followed only later by a contrast between coronals and velars. That is, many children begin with only one lingual place of articulation, which this feature geometry reflects. Typically, they exhibit a velar fronting pattern in which coronal stops substitute for velars. However, the opposite pattern, i.e. coronal backing, is attested in Japanese, where velar stops are more frequent (Beckman et al. 2003), and occasionally in children with phonological disorders (Morrisette et al. 2003). Labials, on the other hand, do not substitute for lingual consonants (Morrisette et al. 2003) except in assimilatory contexts, as in *could be* [kʊb bi] or *boat* [boʊp].

Lingual substitution also occurs in loanword adaptation in adult speech. For example, in a language like Hawaiian that has no coronal stops, [k] substitutes for the coronal obstruents /t/ and /s/ in borrowed words, as in (13) (Adler 2006, Drescher 2009: 200).

(13) Lingual consonant substitution in Hawaiian loanwords

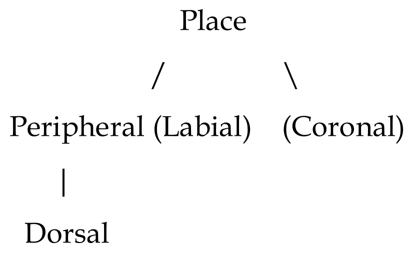
lettuce [lekuke]   *soap* [kope]   *task* [kake]

Substitutions of [k] for /t/ are rare in English, but may occur in borrowings of words with /tl/ onset clusters, since this cluster is not permitted in English. Examples include pronunciations of the Native American tribe Tlingit [klɪŋkit], the Slovak surname *Tlachac* /tlahatʃ/ as [klahatʃ] (Jackie Tlahac, personal communication), and even the invented Klingon language, where the lateral affricate /tɬ/ is borrowed into English as [kl] (Klingon Language Institute, www.kil.org).

The substitution of one lingual place of articulation for another is easily explained if we consider [Lingual] as a feature to which the output should be faithful. When a dorsal is not possible, the next best substitute is a coronal, since it at least preserves the lingual articulation. Similarly, when a coronal is not possible, a dorsal is the next best substitute due to its lingual articulation. Without the Lingual feature node, labials should in principle be an equally good substitute for coronals or dorsals, since all places of articulation are created equal in the feature geometry; however, context-free substitution of labials for coronals is not attested.

This feature geometry model contrasts with one discussed in Rice (1996) (see also Rice and Avery 1995), where Dorsal and Labial are considered to be Peripheral features in contrast to Coronal, a view that arises in the context of phonological acquisition, Rice (1996) proposes that the hierarchy of place features is built up gradually based on the number of contrasts in the child's system, beginning with a Coronal and Peripheral (Labial) contrast, with the Dorsal contrast added at a later point. This featural structure is illustrated in (14).

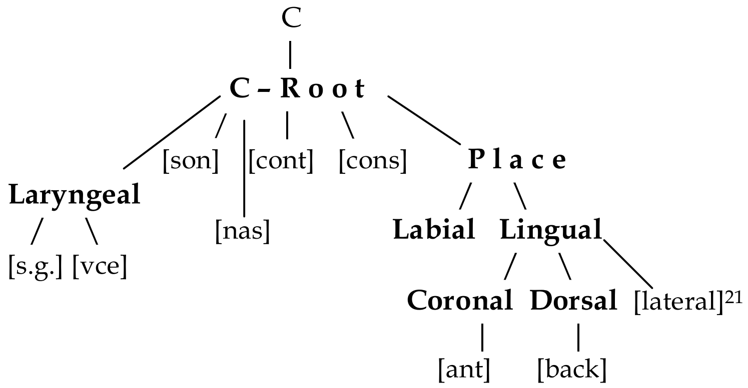
(14) Peripheral node (Rice 1996*)*



However, it is unclear how this structure accounts for the fact that a coronal substitutes for a dorsal (and vice versa, depending on the language and the child), since the Peripheral node groups the features Labial and Dorsal together as having a feature in common, rather than Dorsal and Coronal. While I do not object to the proposal that structure is built up on the basis of contrasts, the fact that many children begin with only one lingual place of articulation leads me to view the development of place contrast as beginning with labial versus lingual, where the specific lingual place is filled in with the child's default lingual place of articulation, typically [Coronal]. The contrast between lingual places of articulation frequently occurs later in development, as documented for receptive language abilities by Brown and Matthews (1997), who use this to justify the use of a [Lingual] feature node in the hierarchy.

I assume the partial feature hierarchy in (15) for consonant features in English. Only features relevant for the analysis of harmony, metathesis, and deletion patterns in this dissertation are included. Feature definitions are given in Appendix A.

(15) Partial consonant place feature hierarchy for English[20]



In Chapter 4, I discuss how the addition of the Lingual node helps explain certain harmony patterns in Grace's data as well as cross-linguistic consonant harmony trends. Before proceeding to a discussion of these patterns, I present the specific constraints and ranking assumptions of the Bernhardt and Stemberger model that are crucial for my analysis.

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[20] Certain minor features such as [constricted glottis] and [distributed] are omitted from this hierarchy since they are not relevant for the present analysis.

[21] The addition of a Lingual node provides a logical place for [lateral] in the feature geometry. Ladefoged (2007) notes that laterality is relevant only for Coronal and Dorsal sounds, and that it would be desirable to capture this in the hierarchy. It has been suggested that [lateral] could be dependent on Coronal (e.g. Blevins 1994, Bernhardt and Stemberger 1998: 93-94) or Sonorant Voicing (Rice and Avery 1991), but in her arguments against feature geometry, Yip (2004) discusses reasons why both of these proposals are problematic. Making [lateral] dependent on the Lingual node seems to avoid these problems as well as the unexplained gap in her typology, which predicts the existence of labial laterals (Yip 2004: 31). I do not discuss the implications of this proposal further since it is not the focus of the present study.

2.2 The constraint set (Bernhardt and Stemberger 1998)

In this section, I provide an overview of the constraints proposed in the Bernhardt and Stemberger (1998) variant of OT. Since most readers will be familiar with standard OT correspondence theory constraints (McCarthy and Prince 1995), I compare and contrast similar constraints in the two frameworks. As in all constraint-based models, there is an inherent tension between constraints that promote the faithful production of the lexical input and constraints on the phonological structure of the output. The latter are typically referred to as markedness constraints. However, the term "markedness" has not always been used in a consistent way, and has often been used as an explanatory label when in fact it is itself in need of explanation (Menn 1983, Hume 2004). Haspelmath (2006) suggests that the use of markedness in phonology should be replaced with explanations based on frequency of use or phonetic difficulty. I generally avoid the term markedness and refer instead to output or production constraints.

A minor difference between the two variants of OT is that Bernhardt and Stemberger flip the usual format of a constraint table (known as a "tableau" in classic OT), placing constraint rankings on the left and candidates for output across the top (rather than vice versa).[22] This format has the practical advantage of leaving ample space for long constraint names (thus avoiding the need for cryptic constraint abbreviations), while also providing a visual representation of constraint rankings, with the highest ranked constraint appearing at the top of the table and the lowest at the bottom. This format is illustrated in (16). The optimal candidate, i.e. the output that surfaces, is indicated with a bolded outline. Cells with constraint violations that are not decisive may be shaded in gray, as in classic OT.

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[22] As is conventional in standard OT, an asterisk marks a constraint violation, and an exclamation point indicates the "fatal" violation that prevents a candidate from surfacing.

(16) Sample constraint table format (Bernhardt and Stemberger 1998)

Input: *boat* /boʊt/	[boʊt]	[doʊt]	[boʊp]
Constraint Name 1	*!		
Constraint Name 2		*!	
Constraint Name 3			*

Other differences between the two variants of OT will become apparent in the discussion of constraints that follows. I begin by addressing the question of the universality of constraints and their grounding. I then present the output and faithfulness constraints of Bernhardt and Stemberger (1998) that will be relevant to my analysis.

2.2.1 Universality and grounding of constraints

The fact that children succeed relatively quickly in the complex task of phonological acquisition has long been taken as evidence of "an innate, highly specific phonological grammar" (Macken 1980: 261). Much work in generative phonology has taken this nativist view, while later connectionist and usage-based models have offered a competing emergentist view. OT is typically viewed as a nativist approach since it presumes a universal set of constraints on output that is present at the outset of the learning process. It is often assumed that universality implies innateness (e.g. Kager et al. 2004). Gnanadesikan (2004) argues that a constraint against complex onsets must be innate, since it causes cluster reduction in English-acquiring children despite the fact that there is no evidence for such a constraint in the language input the child receives.

However, there is an alternative view to account for the same facts. If we assume that "…children possess no innate phonological skills and must learn to do everything" (Stemberger and Bernhardt 1999: 444), then we know that, among other things, infants must learn to plan and produce various articulatory gestures in combination and in sequence. If the coordination of segmental sequences must be learned, it follows that in the initial stage of acquisition, complex onsets will not be possible. The child will begin with simple segments and sequences, and proceed to learn more complex combinations. In this view, universality need not imply innateness.

Following Bernhardt and Stemberger (1998), I adopt the view that we see essentially universal constraints because all humans have the same cognitive and articulatory systems at their disposal. Universal phonological tendencies are reflected in constraints that emerge in each speaker due to the principles of cognitive processing and the physiology of the vocal tract. By assuming that most phonological information is learned rather than innate, their approach has something in common with Evolutionary Phonology (Blevins 2004), which similarly challenges the existence of innate *phonological* knowledge, while allowing for synchronic effects of innate knowledge or processing effects in phonetics and cognitive sciences (see Blevins 2006 for further discussion).

Unlike Blevins, however, Bernhardt and Stemberger maintain a teleological view wherein the grammar seeks to optimize the output. Most output constraints in their framework are cognitive in nature, or "deriving from constraints in information processing" (Stemberger and Bernhardt 1999: 434). All speech planning acts require accessing information, which carries a cost in terms of cognitive resources. The drive to minimize the use of cognitive resources implies constraints against all speech acts that must be overcome to various extents in order to faithfully reproduce the language input.[23] A possible exception to this grounding principle is the set of constraints imposing syllabic structure. Bernhardt and Stemberger acknowledge that the grounding for these constraints is not clear, although I speculate that organizing the speech stream into chunks aids in speech planning.[24] If all constraints are functional, as previously argued by Archangeli and Pulleyblank (1994) and Hayes (1999), there is no need to assume a special innateness for phonological constraints. Output constraints minimize

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[23] An alternative view is that constraints are grammaticised principles encoding phonetic tendencies (Hayes 2004). This differs from Bernhardt and Stemberger's view, in which phonetic considerations play a role in the ranking of constraints only.

[24] Interestingly, prosodic structure is one of two areas of phonology that Blevins suggests may require a universal component, the other being distinctive features (2004: 251).

cognitive resources in order to facilitate speech planning, while faithfulness constraints are motivated by a need to maintain lexical contrast.

2.2.2 Negative constraints on the output

The fact that cognitive resources are required to access the elements necessary for speech production implies constraints against all speech acts, including: 1) producing a gesture; 2) prolonging a gesture; 3) combining two gestures at the same time or 4) in sequence; or 5) immediately repeating a gesture (Stemberger and Bernhardt 1999). Since these constraints militate against various speech acts, they are phrased in the negative. The most basic negative constraint pertains to production of a gesture. As defined in (17), the **Not** constraint can apply to any element of the output, where the set of elements includes feature, timing units and prosodic structure.

(17) **Not**: An element (i.e. feature, timing unit, or other prosodic structure) must not appear in the output; e.g. **Not(+nasal)**, **Not(Dorsal)**, **Not(Coda)**
(cf. *DORSAL, NOCODA, McCarthy and Prince 1995)

The **Not** constraint may prohibit some features entirely in a given phonological system; for example, a high ranking of **Not(Dorsal)** can prevent production of any velar consonants, while a high ranking of **Not(+spread glottis)** can result in a complete absence of /h/ or aspirated stops. Of course, numerous **Not** constraints are routinely violated in phonological systems, since verbal communication requires speech production. Wherever a segment or feature surfaces in violation of **Not** constraints, it is because some higher ranked constraint, usually a faithfulness constraint, forces the production of that element.

The assumption is that a **Not** constraint exists for every feature of a segment, since every element requires some cognitive resources to access and produce. Default feature values, however, require fewer resources to produce than non-default features. This is reflected directly in fixed rankings of **Not** constraints, in that a constraint against a non-default feature values will be ranked above the constraint against the corresponding default value. Thus, for example, we expect the ranking **Not(+nasal) >> Not(-nasal)** for nasality, reflecting the greater amount of cognitive resources required to access the less frequent feature. Similarly, we expect the ranking **Not(Dorsal), Not(Labial)** >> **Not(Coronal)** since [Coronal] is the default place feature in most languages and children. This approach differs somewhat from standard OT, which assumes the innate ranking of constraints against place features given in (18):

(18) Fixed innate ranking of place constraints (McCarthy and Prince 1995)
*DORSAL >> *LABIAL >> *CORONAL

This ranking reflects the common view that [Dorsal] is the most "marked" place feature for consonants, based on evidence from assimilation patterns in the world's languages (de Lacy 2002), the absence of epenthetical dorsal consonants, and the fact that [Dorsal] is frequently acquired later than [Labial] and [Coronal] (Locke 1983). With this in mind, Bernhardt and Stemberger (1998) assume that **Not(Dorsal)** is usually ranked higher than **Not(Labial)**. However, this may vary by child and by language, as noted above. In Grace's case, all three major place features were present at onset of speech. For purposes of my analysis, I will assume that **Not** constraints for both non-default place features [Labial] and [Dorsal] are ranked above **Not(Coronal)**, but will not assume further rankings unless justified by the data.

In addtion to a constraint against producing a gesture, we need a constraint against prolonging a gesture longer than is required by the input. This constraint is perhaps more opaquely named **SinglyLinked**, referring to the linking of a feature to only a single dominating node within the hierarchy, as defined in (19). This constraint thus prevents the spreading of a feature.

(19) **SinglyLinked**: A feature can be linked to only a single higher element in the geometry; i.e. **do not spread a feature** beyond its basic duration;
e.g. **SinglyLinked(Dorsal)**, **SinglyLinked(+continuant)**.
(cf. NO-SPREAD, McCarthy 1997; NOLINK, McCarthy 2008).

Whenever assimilation occurs due to feature spreading, **SinglyLinked** must be ranked below another constraint motivating the assimilation. A low ranking of

SinglyLinked(+nasal), for example, permits spreading of nasality from a nasal vowel to a following oral vowel as in Haitian Creole /bãk/ 'bank' + /la/ (det.) → [bãk.lã] when motivated by another constraint, e.g. a constraint against sequences of vowels differing in nasality. Constraints against sequences of features, which often motivate assimilation, are discussed in 2.2.3.

Bernhardt and Stemberger (1998: 710) indicate that there is no inherent ranking of **SinglyLinked** constraints with respect to each other. However, it seems logical that rankings for **SinglyLinked(F)** would be correlated with the rankings for **Not(F)** constraints; that is **SinglyLinked(Non-default) >> SinglyLinked(Default)**. This ranking reflects the fact that a sequence of non-default feature values requires more cognitive resources than a sequence of defaults.

Thus far we have constraints against the production and extension of speech gestures. The act of combining two (or more) gestures is governed by the constraint in (20) against the co-occurrence of features (Bernhardt and Stemberger 1998: 211):

(20) **NotCo-occurring(A,B):** A and B may not co-occur at the same point in time (such as within the same segment); e.g. **NotCo-occurring(Dorsal,Labial)**, **NotCo-occurring(-sonorant,+voice)**.

This constraint is similar to featural co-occurrence constraints discussed in subsequent OT work (e.g Padgett 2002, Levelt and van Oostendorp 2007), an example being *LATERALDORSAL, which prohibits the co-occurrence of [+lateral] and [Dorsal] in a single segment (Yip 2004). For Bernhardt and Stemberger, these constraints reflect the cognitive resources required to combine features within a segment, and are presumed to exist for all feature combinations. The relative difficulty of specific combinations is reflected in the rankings of these constraints rather than in the constraints themselves. While there is considerable variability across children as to which specific combinations will be most difficult, Bernhardt and Stemberger suggest that the ranking of these constraints is generally correlated with that of the **Not** constraints, in that it is more difficult to combine combination of two non-default features due to the greater amount of cognitive resources required to access these features.[25] Thus we expect a ranking of **NotCo-occurring(Dorsal,Labial) >> NotCo-occurring(Dorsal,Coronal)**, a ranking I later argue is relevant for the acquisition of /j/ before /w/ in Grace's grammar.[26]

The three output constraints outlined in this section are all relevant for the analysis of Grace's phonological development. However, the most important production constraints for the purposes of the present analysis are those related to sequences of features: the constraint against combining different gestures in sequence (**NoSequence**) and the constraint against repeating a gesture (**NotTwice**). These constraints are given special attention below.

2.2.3 Constraints on feature sequences

I argue that constraints against sequences of features are the most important constraints driving Grace's early consonant harmony, metathesis, initial consonant deletion, and cluster reduction. There are two types of sequence constraints defined in Bernhardt and Stemberger (1998): constraints against combining different gestures in sequence (**NoSequence**) and constraints against repeating a gesture (**NotTwice**). The first type is defined in (21):

(21) **NoSequence(A…B)**: Given two adjacent segments, A cannot be in the first segment if B is in the second segment; e.g. **NoSequence(Labial…Dorsal)**.

This constraint reflects a tendency to minimize effort in speech planning. Whether due to the force of inertia preferring to maintain the current position of the articulators or the tendency to anticipate features of a later segment, coordinating a sequence of different features requires additional effort in terms of cognitive resources. Bernhardt and Stemberger (1998) note that they do not find any use for a **NoSequence** constraint referring to two different types of features, such as **NoSequence(Labial…+continuant)**.

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[25] Levelt and van Oostendorp (2007: 167) similarly note that constraints against the co-occurrence of two marked features are evident in acquisition.

[26] This approach is similar to the computational phonological development model in Redford and Miikkulainen (2007), which penalizes multiply articulated segments in calculating the overall articulatory cost of the sounds within a word.

Rather, **NoSequence** constraints are relevant only for feature values along a given featural parameter, e.g. **NoSequence(-continuant…+continuant)**. I therefore revise the constraint definition as in (22).

(22) **NoSequence(A…B) (REVISED)**: Given two adjacent segments, if A and B are different values of a feature, A cannot be in the first segment if B is in the second; e.g. **NoSequence(Labial…Dorsal)**; **NoSequence(-nasal…+nasal)**.

Bernhardt and Stemberger (1998) occasionally use constraints referring to a sequence of a specified place node and any other articulator (which they abbreviate Artic), e.g. **NoSequence(Labial…Artic)**. I do not use this more generic version of the constraint since "Articulator" does not refer to a feature or node in the place hierarchy. However, assuming a Lingual feature node, **NoSequence(Labial…Artic)** can be restated as **NoSequence(Lingual…Labial)**, and the reverse as **NoSequence(Labial…Lingual)**. Given this, and the fact that **NoSequence(Dorsal…Artic)** can be broken down into the constraints **NoSequence(Dorsal…Labial)** and **NoSequence(Dorsal…Coronal)**, I dispense with any constraints referring to a generic Articulator in the interests of keeping constraints in the system to a minimum.

A common repair for a **NoSequence** constraint violation is assimilation, since one way to avoid a sequence of differing features is to change one of the features to match the other. For example, given an underlying sequence of /pk/ as in *napkin*, assimilation of the /p/ to /k/ as in [nækːɪn] satisfies **NoSequence(Dorsal…Labial)**. However, **NoSequence** may also be satisfied by featural metathesis, if it is the particular order of the features in question that is dispreferred. An example of this response occurs in the Kui language, where /bluk+pa/ surfaces as [blupka] (Hume 2004), implying a ranking of **NoSequence(Dorsal…Labial) >> NoSequence(Labial…Dorsal)**. A third option for avoiding a **NoSequence** violation, although somewhat drastic, is segmental deletion, which eliminates the sequence by deleting one of the features altogether. Bernhardt and Stemberger indicate that they found "no clear-cut examples in which segment deletion is a response to sequence constraints, but they may exist" (1998: 549). In Chapter 5, I will argue that a sequence constraint sometimes motivates deletion in early phonological acquisition, depending on the ranking of relevant output and faithfulness constraints.[27]

NoSequence constraints may be defined for either root adjacency or tier adjacency, assuming planar segregation of consonants and vowels (see Macken 1980 and Archangeli 1985 for discussion). That is, the features in question may occur in a sequence of immediately adjacent segments (i.e. adjacent Root nodes) or in a sequence of segments adjacent on the consonantal or vowel tier with intervening segmental material. I will use both types of **NoSequence** constraints, with **NoSequence$^{\text{TIER}}$** being relevant for processes applying to consonants over an intervening vowel, such as consonant harmony and long-distance metathesis, while **NoSequence$^{\text{ROOT}}$** will be relevant for onset cluster reduction (involving immediately adjacent consonants). Since the relevant type of **NoSequence** constraint will be clear from the context, I do not typically specify whether the constraint applies to segmental or tier adjacency. With respect to a given feature, I expect a child to learn to coordinate tier-adjacent sequences before root-adjacent sequences; that is, it must be possible to coordinate a sequence of differing consonantal features within a syllable if the sequence is to be possible in immediately adjacent segments within a cluster. This proposed progression from tier adjacency to root adjacency for the acquisition of consonant sequences is discussed further in 5.3.2.

As with feature combinations, there is considerable variation as to which feature sequences children find difficult, but sequences of non-default features may require more cognitive resources than those involving default features. Thus for example, **NoSequence(Dorsal…Labial)** may be ranked above **NoSequence(Dorsal…Coronal)**. This would explain the observation that obstruent clusters in English never contain more than one non-coronal (Yip 1991), resulting in English onsets such as /sp, sk/ but not /fp, fk/. Rankings may also be related to the frequency of particular sequences in

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[27] Another possible repair for a **NoSequence$^{\text{ROOT}}$** violation would be insertion of a segment to break up the sequence, e.g. vowel epenthesis in /blæk/ → [bəlæk]. However, epenthesis appears only rarely in child phonology, probably due to constraints limiting word length and complexity and constraints against initial unstressed syllables.

the adult language input the child receives. For example, Bernhardt and Stemberger (1998) suggest that the high ranking of **NoSequence(Coronal…Labial)** motivating anticipatory labial harmony in many English-acquiring children may be related to the absence of adjacent Coronal…Labial sequences (e.g. *tp/dp word-medially) in adult English.[28] The relative difficulty of particular sequences and their relation to common harmony and metathesis patterns is discussed further in Chapter 4.

Bernhardt and Stemberger note that **NoSequence** constraints most often affect two place features. Manner features seem to be affected least of all. In fact, while place, nasality, and voicing commonly participate in assimilatory processes across the world's languages, manner features related to the openness of the vocal tract are not prone to assimilation, especially when adjacent, as evidenced in the preference for cycles of closure and sonority peaks in syllables. Sonority and its related constraints will be discussed further in 2.2.4.

The other type of constraint on sequences of features proposed in Bernhardt and Stemberger (1998) is the **NotTwice** constraint, defined in (23), which prohibits the repetition of a gesture (represented here by a feature).

(23) **NotTwice**: A feature (or feature node) may not appear twice if the two tokens are adjacent, e.g. **NotTwice(Labial)**, **NotTwice(+continuant)**.

NotTwice can be seen as analogous to the Obligatory Contour Principle (OCP), which bans adjacent identical features on the same tier in underlying representations (Leben 1973, Goldsmith 1976, McCarthy 1986, Yip 1988).[29] As defined in (23), this constraint is *not* violated when two adjacent segments *share* a single token of a feature, the representation that is generally assumed in feature assimilation. As a result, like

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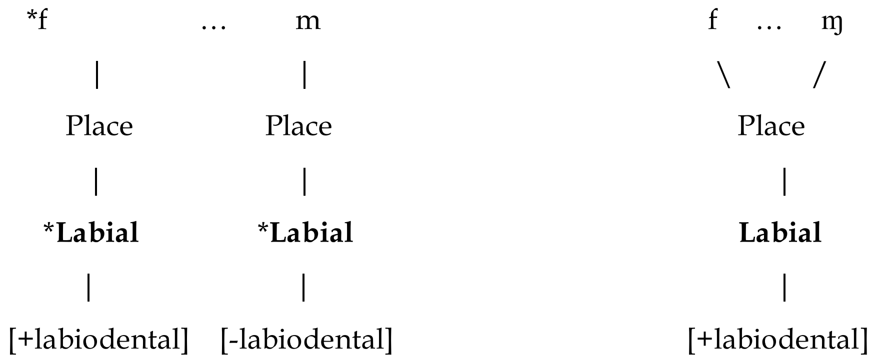
[28] This gap in attested adjacent sequences may also be related to the fact that the cues for a coronal stop are easily lost in the context of a following labial due to gestural overlap. For example, I have often misheard politician Rod Blagojevich's name in radio broadcasts as "**Rob** Blagojevich," despite knowing who he was. Sequences that are difficult to perceive are not likely to survive language transmission over generations (see Blevins 2004).

[29] In Section 2.2.4, however, I propose a distinction between **NotTwice** and **Agree** constraints. As redefined in 2.2.4, **NotTwice** is not analogous to the OCP.

NoSequence constraints, this constraint can motivate assimilation. For example, Gwendolyn's early assimilation of labiodental nasals in the context of a labiodental fricative, as in *small* [fɱaʊ] (Bernhardt and Stemberger 1998: 562), could be attributed to a high ranking of **NotTwice(Labial)**. This constraint was active in her grammar for both root and tier adjacency, given that the assimilation pattern extended to non-adjacent labials within an utterance if there was no intervening C-Place node, e.g. *small home* [fɱaʊ hoʊɱ] but *small comb* [fɱaʊ tʰoʊm]. The effects of **NotTwice(Labial)** are illustrated in the partial feature hierarchy in (24), where a sequence of two different labials (*fm) is prohibited by the constraint, while sharing of all place features, including labiodental, is permitted.

(24) (a) Violation of **NotTwice(Labial)** (b) No violation: shared features



Sequences of differing coronal specifications may also be avoided due to **NotTwice(Coronal)**, as in the anticipatory assimilation of concatenated sibilants in the phrase "is she?" [ɪʒ ʃi], or the depalatalization of the affricate in the local pronunciation of *Hodgson Road* as [hadsən][30] (see Yip 1988 for additional examples).

A difference between **NoSequence** and **NotTwice** constraints is that while both types of constraints can motivate assimilation or deletion, only **NoSequence** constraints can motivate metathesis. Changing the order of features will not improve the output with respect to a **NotTwice** constraint. In the analysis to follow, I will show that both types of sequence constraints underlie the harmony patterns in Grace's data and contribute to

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[30] This pronunciation of Hodgson Road is used by local residents in Lino Lakes, Minnesota.

some of her early initial consonant deletion, while her occasional metathesis results from a high ranking of a specific **NoSequence** constraint.

The use of constraints on sequences of features to account for harmony contrasts with various constraints used for this purpose in other OT analyses. ALIGN[FEATURE] constraints have been used to account for consonant harmony in phonological acquisition (Velleman 1996, Goad 1996, Fikkert and Levelt 2008, Bat-El 2009), as well as for long-distance metathesis (Velleman 1996). However, the grounding for aligning a particular place feature with the left or right edge of a word is not clear. Furthermore, as pointed out in Padgett (2002), using alignment to motivate feature spreading incorporates directionality into the constraint, when directionality can follow from other independent factors. Bernhardt and Stemberger (1998) generally avoid **Alignment** constraints if the patterns can be explained in other ways, due to their potential to overgenerate patterns that are not attested and the lack of grounding for such constraints.

In her account of vowel harmony, Kaun (1995) uses an EXTEND[FEATURE] constraint restricted to operating on contrastive feature values, which states that a feature such as [+round] must be associated with all vocalic positions within a word. Padgett (2002) similarly invokes a "spreading imperative" in the form of a SPREAD(FEATURE) constraint requiring that a feature be multiply linked or extended in its domain in the output. A drawback to these constraints is that they seem to specify a particular phonological process rather than a general constraint on the output. Padgett (2002) notes that SPREAD(FEATURE) may ultimately need to be reduced to more fundamental and functionally motivated constraints.

Constraints such as SHARE-FEATURE (e.g. SHARE-PLACE, SHARE-LATERAL—Yip 2004) and AGREE-FEATURE have also been used to motivate various assimilation processes, including long-distance consonant agreement in adult languages (Rose and Walker 2004) and consonant harmony in children (Pater 1997, Pater and Werle 2003). One definition of a place agreement constraint is given in (25).

(25) AGREE-PLACE (Pater and Werle 2003):
Consonants must agree in place of articulation.

The use of the term "agree" in the constraint name is somewhat awkward, as it may be interpreted as a mandate for assimilation, once again implying a process rather than an output structure. However, if interpreted as a constraint prohibiting a sequence of segments that differ in a given feature, then it would also be satisfied by deletion (but not metathesis). I return to a discussion of the **Agree** constraint in Section 2.2.4.

The use of constraints on sequences of features to motivate the major processes in Grace's early phonology highlights the interconnectedness of these processes and how they are related to the acquisition of consonant sequences. All of these processes can be seen as arising out of difficulties in the planning and execution of consonant feature sequences. Constraints on sequences of features can lead to consonant harmony, long-distance metathesis, or initial consonant deletion, depending on the rankings of relevant faithfulness constraints.

2.2.4 Sonority-related constraints

The relative sonority of segments has long been cited to account for phonological patterns of syllable structure in which less sonorous segments are preferred in syllable margins and more sonorous segments are preferred in syllable peaks (Sievers 1881, Jesperson 1904, cited in Parker 2002). Segments are typically placed in the common sonority scale given in (26) (e.g. Selkirk 1984, Blevins 1995), where stops are the least sonorous consonants, and glides are most sonorous:

(26) Sonority Scale: stops < fricatives < nasals < liquids < glides

A standard OT approach to the sonority has been to stipulate a hierarchy of fixed constraint rankings governing the occurrence of particular segments in syllable peaks and margins (Prince and Smolensky 2004/1993). While Prince and Smolensky originally formulated these constraints in terms of individual segments (e.g. *Margin/r), they are more commonly given in terms of segment types, as in the following hierarchy specific to syllable onsets:

(27) Onset sonority hierarchy in OT (Pater 1997)
*Glide/Ons >> *Liquid/Ons >> *Nasal/Ons >> *Fricative/Ons

In practice, sonority preferences are often attributed to more general constraints such as those in (28):

(28) Examples of sonority-related constraints (Holt 2004)
a) MINDISTSON (MINIMAL DISTANCE IN SONORITY): There must be a minimum difference in sonority between members of a syllable onset.
b) SSP (SONORITY SEQUENCING PRINCIPLE): Between any member of a syllable and the syllable peak, only sounds of higher sonority rank are permitted.

The hierarchy given in (27) generally holds true, and the constraints given in (28) are excellent statements of common phonological patterns seen in adult languages. However, a problem shared by both of these approaches is that they merely stipulate fixed rankings or restate common patterns rather than actually motivating or explaining them. A valid criticism of sonority in phonological models is that the sonority hierarchy is often used as an explanation for various patterns, when in fact the hierarchy itself is in need of explanation (Ohala and Kawasaki-Fukumori 1997). At a more basic level, it is also important to clarify what is meant by sonority, since a variety of sonority correlates have been proposed, including openness of the vocal tract, amplitude, and perceptibility, among others (see excellent summary in Parker 2002).

Bernhardt and Stemberger (1998) view sonority preferences as emerging from closed-open cycles of the vocal tract in which the optimal syllabic element (or syllable peak) has an open vocal tract, while the optimal non-syllabic element has a closed vocal tract. This view is consistent with the Frames/Content theory of speech development (Davis and MacNeilage 2002; MacNeilage and Davis 1990), which views the CV syllable preference of babbling, early speech and adult languages as arising from early basic mandibular oscillation patterns that are co-opted for speech patterns, in which the closed state corresponds to consonant elements and the open state corresponds to vowel elements.[31] Each “frame” refers to one oscillation of the mandible, while the “content” refers to independent movements of the tongue and other vocal tract components for the articulation of specific consonants and vowels. A more recent computational model of phonological development similarly recognizes the role of these cycles, nesting the movements of the lips, tongue and glottis within the cyclic movement of the jaw, “conceived of as the articulatory manifestation of the rhythm pattern in speech” (Redford and Miikkulainen 2007: 747). All of these approaches share a view of the centrality of open-closed jaw cycles in phonological development and derivation of the syllable from the boundaries of a single open-closed jaw cycle.

This pattern of oral closure alternating with an open vocal tract is reflected in the prevalence of oral stops, especially as onsets, in babbling and early speech (see Bernhardt and Stemberger 1998, Gildersleeve-Neumann et al. 2000, Fikkert 1994, and Lee, Davis and MacNeilage 2008).[32] The preference for initial closure makes an oral stop the ideal onset, and leads to the emergence of constraints preferring closed manner features in this position. These constraints belong to a family of positive co-occurrence constraints defined in (29):

(29) **Co-occurring(A→ B)**: The presence of element A implies B. In other words, B must co-occur with A; e.g. **Co-occurring(+sonorant→ +voice)**.[33]

Specifically, the three constraints in (30) formalize the preference in syllable onsets for manner features associated with complete closure of the vocal tract:

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[31] However, Davis and MacNeilage (2002) overtly criticize the use of sonority in phonological analysis as an abstract, perceptually based concept.

[32] Interestingly, Davis and MacNeilage (2008) study showed that while stops are already the most frequent consonant type in Korean (33% stops, 28% nasals, 11% fricatives, 9% affricates), mothers used them even more frequently in Infant Directed Speech, with a corresponding decrease in number of fricatives (37% stops, 6% fricatives).

[33] Positive co-occurrence constraints can be used to fill in predictable (redundant) features that are implied by another feature; see discussion in 2.2.5.

(30) Constraints governing sonority preferences in onsets[34]

Co-occurring(Onset→ +consonantal): A syllable onset should be [+consonantal].

Co-occurring(Onset→ -sonorant): A syllable onset should be [-sonorant].

Co-occurring(Onset→ -continuant). A syllable onset should be [-continuant].

These simple constraints can derive many of the patterns of allowable onsets and onset cluster reduction that are typically attributed to sonority. An advantage to this approach over a fixed hierarchy of constraints against segment types is that it captures generalizations on the basis of phonological features. For example, in cluster reduction, variation in the ranking of these constraints can explain variation in cluster reduction patterns for /s/+nasal onset clusters, where some children prefer to retain the fricative in *snow* [soʊ] to satisfy **Co-occurring(Onset→ -sonorant**), while others prefer to retain the nasal as in *snow* [noʊ] to satisfy **Co-occurring(Onset→ -continuant**).

These constraints also provide a principled way of understanding the otherwise puzzling case of a child who acquired liquids and glides in clusters (e.g. *train* 'train' /trɛɪn/ [tlɛɪ]) earlier than in word-initial singleton onsets (Fikkert 1994, cited in Bernhardt and Stemberger 1998: 501). As explained by Bernhardt and Stemberger, this pattern can be explained if the faithfulness constraints for liquid and glide features are ranked above the corresponding **Not** constraints, but **Co-occurring(Onset→ -sonorant**) is highly ranked. In such a scenario, realization of these consonants would generally be permitted except in word-initial onsets.

Although not explicitly discussed in Bernhardt and Stemberger (1998), preferences for manner feature sequences may also be seen as emerging out of closed-open cycles of the

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[34] Bernhardt and Stemberger apply these constraints more generally to syllable margins, noting that in the case of codas, conflicting co-occurrence constraints for margins and rimes apply (see Bernhardt and Stemberger 1998: 214-215 for discussion). I conservatively apply these constraints to onsets only, since this is the relevant syllable position for the analysis of Grace's data. (While initial fricative and glides were prohibited in onsets, they were permitted in codas.)

vocal tract. If the ideal onset is maximally closed and the ideal syllable peak is maximally open, this leads to a preference to maximize manner contrast between adjacent segments, and therefore a preference for avoiding sequences of adjacent segments with the same manner feature.[35] To illustrate, in the ideal CV syllable consisting of an oral stop+vowel sequence, there are no repetitions of manner features since the segments differ maximally in vocal tract aperture.

(31) Maximization of manner contrast in a stop+vowel sequence

Stop	+	Vowel
[+consonantal]		[-consonantal]
[-sonorant]		[+sonorant]
[-continuant]		[+continuant]

This sequencing preference could be reflected in **NotTwice** constraints prohibiting the repetition of adjacent aperture features, such as **NotTwice(+sonorant)**. However, as defined above, **NotTwice** is only violated by *separate* adjacent tokens of the feature in question, meaning that adjacent segments with a shared, doubly-linked [+sonorant] feature would not violate **NotTwice(+sonorant)**. This abstract distinction seems undesirable, as we have not eliminated the sequence of consonants with the same manner feature. This discussion highlights a contradiction of sorts: for speech planning purposes, it is easier for adjacent segments to share features; however, for purposes of perpetuating the closed-open cycles of the vocal tract, it is more optimal for adjacent segments to differ in aperture.

Rather than conflate these different functions under the same constraint name, I propose using **NotTwice** to prohibit any sequence of consonants with the same feature value (often an aperture feature), and using an **Agree** constraint to prohibit a sequence of

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[35] As highlighted in Smith (2003), another functional motivation for favoring a low-sonority onset followed by a high-sonority syllable peak is the resulting salience of the spectral patterns in the transitions (Stevens 1989, Ohala 1992, Delgutte 1997). Rapid changes in spectral patterns are most easily perceived and therefore more likely to survive language change over generations, leading to a high frequency of these syllable types in the language input the child receives. This in turn reinforces the preferences that emerge from the closed-open jaw cycles.

consonants that differ in a specified feature, similar to AGREE-FEATURE constraints in other analyses of harmony (e.g. Rose and Walker 2004, Pater 1997, Pater and Werle 2003). A minor difference is that **Agree** as defined here does not set up an agreement relationship between consonants within a word (cf. Rose and Walker 2004); rather, it prohibits a sequence of consonants that do not match in a given feature. As such, it may be satisfied by either assimilation or by segmental deletion. These constraints are redefined in (32) and (33).

(32) **NotTwice(F)**: A feature value F may not appear twice in a sequence of adjacent segments within a prosodic domain (e.g. a syllable or onset);
e.g. **NotTwice(-sonorant)**, **NotTwice(+continuant)**.

(33) **Agree(F)**: A sequence of segments differing in the feature F is prohibited;
e.g. **Agree(Place)**, **Agree(voice)**.

The difference between these two constraints is illustrated in (34), which depicts violations of each constraint.

(34) Sample violations for sequence constraints

a) **NotTwice(F)**
C C
| |
[+F] [+F]*

b) **Agree(F)**
C C
| |
[+F] [-F]*

Both constraints can be satisfied by either assimilation or deletion of one of the segments. **Agree(F)** plays an important role in the analysis of both consonant harmony and deletion to follow, while **NotTwice(F)** for aperture features is more important for the analysis of onset cluster acquisition.

To illustrate the role of **Agree(F)** in child phonology, consider a child who produces [l] in isolation, but not in sequence with another consonant within a word. My son Benjamin, for example, could produce [l] as early as 1;1 in the syllable [la], but was unable to produce it in sequence with another consonant, where it was replaced by a coronal stop. Amahl had a similar pattern from 2;6-2;11 (Smith 1973), as shown in (35).

(35) Lateral production difficulties in a sequence

a) Benjamin: *la* [la] BUT *light* [daɪt], *lunch* [dʌnts][36]
b) Amahl: *hello* [ɛluː] BUT *light* [dait], *lash* [dæt]

This otherwise puzzling pattern receives a logical explanation from sequence constraints for laterality. While these children were capable of producing a lateral as the only consonant within a word, a sequence of consonants differing in laterality caused a speech planning difficulty. This can be reflected in a high ranking of **Agree(lateral)**, which resulted in either stop substitution or initial consonant deletion (e.g. *hello* [ɛluː]) when another consonant occurred within the word.[37]

An additional function of the **NotTwice(F)** constraint used in the analysis below is to prohibit the repetition of a non-default feature within a prosodic domain. For example, one token of [+continuant] may be permitted to surface due to faithfulness constraints, but repetition of this non-default feature seems to place an additional burden on the production system that is greater than a second violation of **Not(+continuant)**. Cumulative effects of such constraints seem to be evident in prohibiting sequences of consonants with multiple non-default features within a word. I suspect that this is the reason that the fictitious place names *Thoth* and *Zuz* sound odd or foreign, and there are no native English words like this. This particular function seems to serve the purpose of local constraint conjunction (Smolensky 1995), proposed in OT to capture effects in which two violations of a constraint seem to trump a higher ranked constraint. The local conjunction of the constraint with itself allows the conjoined constraint to be ranked higher than the simple constraint. Local constraint conjunction has been criticized, however, for expanding the possible constraint set in too many ways, thereby overgenerating grammars (see Padgett 2002 for discussion). The use of **NotTwice[F]** to

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[36] At one point, puzzled by Benjamin's inability to produce [l] in other words, I attempted to promote the transfer by modeling "la, la, la… light!" which merely elicited (somewhat to my frustration) utterances like [la la la daɪt]. However, he did begin producing [l] in these contexts about a week after my apparently futile attempts to encourage their production.

[37] An alternate way of satisfying **Agree(lateral)** would be lateral harmony, as in *yellow* [lɛluː] (Smith 1973). Such a repair may be prevented by a high ranking of **SinglyLinked(+lateral)**.

prohibit repetition of a non-default feature value serves the same purpose without running into the problems of unrestricted constraint conjunction.

2.2.5 Faithfulness constraints

In addition to the production constraints defined above, key to the analysis of Grace's data will be a set of faithfulness constraints that reflects the role of default and non-default features in the phonology. In this section, I present the faithfulness constraints of Bernhardt and Stemberger (1998), noting how they differ from those of standard OT correspondence theory (McCarthy and Prince 1995). In a departure from Bernhardt and Stemberger (1998), however, I distinguish between two types of faithfulness constraints, one mandating preservation of a non-default feature in the output, and the other mandating identity of features between input and output segments.

The primary faithfulness constraint of Bernhardt and Stemberger (1998) pertains to survival of elements from the input to the output, defined in (36).

(36) **Survived**: An element in the underlying representation must be present (i.e. survive) in the output; e.g. **Survived(Dorsal)**, **Survived(C-Place)**.

The **Survived** constraint is analogous to the OT correspondence theory constraint MAX (McCarthy and Prince 1995), which states that every element in the input string should have a correspondent (or be **max**imized) in the output. Although the MAX constraint typically applies to whole segments, McCarthy and Prince (1995: 265) have suggested that features may also stand in correspondence, and MAX[FEATURE] has been used to account for the preservation of specific features such as [+voice] or [Labial] in the output (e.g. Lamontagne and Rice 1995, Lombardi 1998, 2001, Zoll 1998, Fukuzawa 1999, Pater 2002, Gnanadesikan 2004, Fikkert and Levelt 2006), as well as for the preservation of a feature node such as Place (McCarthy 2008).[38]

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[38] The use of segmental-specific MAX constraints such as NASMAX and OBSMAX in the analysis of *NC̥ violations (Pater 1999) similarly suggest feature preservation constraints (although deletion of the nasal rather than the obstruent could simply be attributed to **Not(Nasal)**).

Independent **Survived** constraints apply to all elements in the underlying representation of a segment, including its contrastive features, its Root node, its Place node, and its timing unit (V or C). An example of the independent role of **Survived(C)** is the reduction of /s/+stop clusters by one child to a long fricative [sː] (Allerton 1976, cited in Ringo 1985). **Survived(C-Place)** ensures that a consonant with an underlying place node will have some place feature in the output; otherwise, a glottal may surface, as in debuccalization of coda /s/ to [h] in many Spanish dialects. **Survived(C-Root)** ensures that a consonant will have manner features. In the absence of any other place and manner specifications, the default feature values [Coronal], [+consonantal], [-continuant], etc. will be filled in due to the low ranking of **Not** constraints against these features. Since **Survived** constraints apply only to features that are specified in the underlying representation, they never apply to defaults.

The implications of default underspecification for the relative rankings of **Survived(F)** and **Not(F)** constraints are illustrated in (37), taking [continuant] as an example. In order for a fricative to surface, **Survived(+continuant)** must be ranked above **Not(+continuant)**, which in turn is ranked above **Not(-continuant)**. With this ranking, the non-default value [+continuant] will appear only if specified in the lexicon, while the default [-continuant] will surface in the absence of a [+continuant] specification due to the low ranking of **Not(-continuant)**.

(37) Relative ranking of **Not** and **Survived** constraints for continuancy

Survived(+continuant) >> Not(+continuant) >> Not(-continuant)

There is no inherent ranking among **Survived** constraints for different features. However, if a ranking of **Not(Dorsal) >> Not(Labial)** obtains, as is evidenced by the later acquisition of velars in many children, faithful production of these features will entail a ranking of **Survived(Dorsal) >> Survived(Labial)**. There is evidence for this ranking in some children's harmony patterns in which labials assimilate to velars (e.g. Amahl, Smith 1973; Trevor, Pater 1997; Molly, Vihman and Velleman 1989).[39]

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[39] Interestingly, the opposite pattern, in which velars consistently assimilate to labials, does not seem to be attested. The only apparent cases of consistent velar to labial assimilation are actually

Importantly, the low ranking of **Not** constraints for default features combined with **Survived** constraints for non-default features explains why [Coronal] is the most likely place feature to be *inserted*, while it is also the most likely feature to be *replaced* in assimilation processes such as consonant harmony, where non-default features spread. For feature insertion, the system will prefer to violate the lowest ranked **Not** constraint, resulting in coronal epenthesis,[40] while for feature assimilation, **Survived** constraints for non-default features will favor preservation of either [Dorsal] or [Labial] at the expense of [Coronal]. Preservation of the non-default feature in spreading is illustrated in (38) for consonant harmony in *coat* [koʊk]. If a highly ranked **Agree(Lingual)** constraint prohibits a sequence of different lingual consonants, the **Survived** constraints will select assimilation of [Dorsal], the non-default feature, over coronal, in violation of **SinglyLinked(Dorsal)**.

(38) Preservation of non-default feature in spreading

coat /koʊt/	[koʊt]	[toʊt]	[koʊk]
Agree(Lingual)	*!		
Survived(Dorsal)		*!	
Not(Dorsal)	*		*
SinglyLinked(Dorsal)			*
Not(Coronal)	*	*	

The faithful candidate cannot surface due to highly ranked **Agree(Lingual)**. Since [Coronal] is the default place feature, there is no **Survived(Coronal)** constraint, and

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cases in which velars have not yet been acquired (e.g. Berg 1992). This suggests articulatory reasons to disprefer dorsal consonants, leading to their low frequency in most languages, and may explain why many languages show evidence of a ranking of **Survived(Dorsal) >> Survived(Labial)** in their assimilation patterns (de Lacy 2002).

[40] If the grammar does not require a place feature for the segment, glottal insertion is an alternative.

Survived(Dorsal) will instead favor the non-default feature [Dorsal] in the output. This consonant harmony example further illustrates an advantage of the present model. Default underspecification and the independently grounded constraints on sequences of features discussed in 2.2.3 together derive the insights that Kaun (1995) stipulated by restricting the harmony-specific constraint EXTEND[FEATURE] to contrastive features. The preference to minimize cognitive resources in speech planning leads to a preference for feature agreement, and the fact that contrastive non-default features are underlyingly specified, generating an applicable **Survived** constraint, leads to the spreading of only these features and not others.

Like MAX[FEATURE], **Survived(F)** contrasts with IDENT[FEATURE] (McCarthy and Prince 1995 and much subsequent work within OT), which requires that correspondent segments have identical values for a given feature. If there is no corresponding segment in the output, however (i.e. when a segment deletes), IDENT is vacuously satisfied. For example, given the input *knock* /nak/, the output [nat] would violate IDENT[PLACE], while deletion of the coda consonant as in [na] would violate MAX (for segments) but not IDENT[PLACE], since there is in fact no segment in the output corresponding to the underlying /k/. By contrast, deletion of coda /k/ would violate **Survived(C-Root)** and **Survived(Dorsal)**. The use of **Survived** constraints thus reflects the fact that segmental deletion entails loss of all phonological information encoded in the segment's features, an insight that is lost with the use of IDENT. The use of IDENT[PLACE], which is equally violated by any change in place feature, would also fail to account for the preservation of non-default features over default features in assimilation, shown above in (38).

Survived constraints also allow us to account for the preservation of non-default features on an entirely different segment in the output. This is evident in some particularly striking examples of non-default feature migration from the child phonology literature, given in (39) and (40).

(39) Migration of non-default place features [Dorsal] and [Labial]

a. *dog* [ga] (Compton and Streeter 1977)
b. *tok* [kɔ] (Dutch, Fikkert 1994)
c. *coffee* [baki] (Ingram 1974)
d. *quick* [kip] *squeaky* [kiːpiː] *twice* [daɪf] (Smith 1973)
e. *manzana* 'apple' [mana] *Fernando* [mano] (Spanish, Macken 1978)

(40) Migration of non-default manner feature [+nasal]

a. *smoke* [fõːk] (Bernhardt and Stemberger 1998: 393)
b. *spank* [smæ̃k] (Ringo 1985)
c. *lunch* [nats] (Velten 1943: 287)

Bernhardt and Stemberger (1998) prefer not to posit both **Survived** and **Identical** constraints for features due to the redundancy this introduces to the system. For example, /kæt/ pronounced as [tæt] violates both **Survived(Dorsal)** and **Identical(Place)** if both types of faithfulness constraints are assumed in the framework. It is clear that **Survived(Feature)** constraints are needed, and therefore Bernhardt and Stemberger prefer to dispense with **Identical** constraints. However, they note a few cases in which data are handled more elegantly with **Identical** than **Survived**, and leave it as an open question whether this constraint is needed (1998: 169).

Rather than dispense with **Identical** constraints altogether, I propose that both types of faithfulness constraints are needed, but serve different functions. **Survived** constraints apply exclusively to non-default features specified in the underlying representation. However, there is evidence from substitutions for faithfulness to predictable non-default features as well. For example, although the features [+sonorant], [+continuant] and [+voiced] are entirely predictable for a segment specified as [-consonantal] (i.e. a glide), common substitutions when glides are prohibited in a child's system include voiced stops, voiced fricatives, liquids, and nasals (Bernhardt and Stemberger 1998: 314), each of which preserve one or more of these predictable features. Featural identity matters in substitutions, even when the features in question are predictable for the underlying segment and need not be specified.

In light of this, I suggest a special role for **Identical** constraints in the model. While **Survived(F)** reflects the strength of the connection to an underlying specified non-default feature, **Identical(F)** evaluates the suitability of a segment as a substitute. As such, **Identical(F)** can apply to *predictable* non-default features associated with a given segment. Even though such features may be underspecified, their presence forms part of the speaker's phonological knowledge of segments: nasals and laterals are sonorant; sonorants are voiced; glides are [+continuant]. It is therefore desirable to be faithful to these features if a segmental substitution is necessary. Since **Identical** constraints are vacuously satisfied in cases of deletion, they will only play a role in determining the optimal substitute for a segment prohibited by some other constraint. The distinction between these two constraints will become crucial in Chapter 5, when I examine cases in which the grammar must decide between substitution and deletion of an initial consonant in response to a constraint against a sequence of features.

Only **Identical[F]** can apply to *predictable* non-default features. The predictability of certain non-default features can be formalized in terms of positive co-occurrence constraints, with examples given in (41).

(41) Common high-ranking co-occurrence constraints

Co-occurring(+sonorant→ +voiced): Sonorants should be voiced.

Co-occurring(+lateral→ +sonorant): Laterals should be sonorant.

Co-occurring(Labial,-sonorant,+continuant→ +labiodental): Labial fricatives should be labiodental.

Given the existence of voiceless sonorants, lateral fricatives and bilabial fricatives in some languages (and children), these co-occurrence constraints are not absolute, but merely tend to be highly ranked. In some cases, however, a non-default feature is strictly implied by another non-default feature because it is a property of any segment with that feature. For example, nasal stops are [+sonorant] by definition, since unobstructed airflow through the nasal cavity prevents any rise in supraglottal pressure that would inhibit voicing. Similarly, any [-consonantal] segment, involving relatively unimpeded airflow through the oral cavity, is by definition [+continuant], having continuous airflow. I take the implicatures in (42) to be immutable, and therefore formulate them as statements of fact rather than rankable co-occurrence constraints. Since the Lingual feature node introduced in Section 2.1.2 is similarly entirely predictable based on the features [Dorsal] and [Coronal], I include [Lingual] in these feature implications.

(42) Mandatory feature implications
  a) [+nasal]→ [+sonorant]: Nasals are sonorant.[41]
  b) [-consonantal]→ [+continuant]: Glides are [+continuant].
  c) Coronal→ Lingual: Coronals are lingual.
  d) Dorsal→ Lingual: Dorsals are lingual.

Identical[F] can apply to these predictable non-default features, while **Survived[F]** is reserved for non-default features specified in the underlying representation. Although this means of distinguishing the applicability of IDENT[FEATURE] versus MAX[FEATURE] has not been explicitly stated in the OT literature (to my knowledge), it is striking that arguments for MAX[FEATURE] constraints (analogous to **Survived**) have been based on contrastive non-default features that are prone to feature spreading and migration, such as [+voice], [+nasal], [Labial] and [Dorsal] (Lombardi 2001, Pater 2002, Gnanadesikan 2004, Fikkert and Levelt 2008). Restricting the application of **Survived** constraints to underlyingly specified non-default features provides a principled way of determining which type of faithfulness constraint is applicable. **Survived** constraints always apply to contrastive non-default features and are violated by deletion, while **Identical** constraints can apply to predictable features and are violated only by substitution. By having a principled distinction between the two types of faithfulness constraints, each serves a unique purpose, and we avoid redundancy of constraints in the system.

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[41] A high ranking of **Co-occurring(+sonorant→ voice)** and the property of nasals being [+sonorant] together serve the same purpose as the constraints SONVOI and NASVOI (Ito, Mester and Padgett 1995), which promote voicing for sonorants and nasals respectively.

Thus far we have established two types of faithfulness constraints: **Survived** constraints, which preserve elements in the output by applying to underlying specified features and nodes (e.g. Root, Place); and **Identical** constraints, which govern the faithfulness of substitute segments with respect to non-default features. Standard OT (McCarthy and Prince 1995) uses an additional faithfulness constraint to prevent epenthesis known as DEP, which requires that every element of the output be **dep**endent on a correspondent in the input. However, as defined above, the **Not** constraint already prohibits production of elements in the output that are not required by other constraints, making a separate DEP constraint superfluous. Positing only a **Not** constraint against any production of an element rather than constraints against both production and insertion keeps the constraints in the system to a minimum.

While **Survived** governs the preservation of features and timing units, it does not say anything about where they appear in the output. Bernhardt and Stemberger (1998) use a general **Contiguity** constraint to prevent any change in the contiguity of elements from the input to the output.

(43) **Contiguity**: Elements that are contiguous in the underlying representation must be contiguous on the surface. Violated by word-internal epenthesis (e.g. /blæk/ → [bəlæk]), word-internal deletion (e.g. /stap/ → [sap]), and most cases of metathesis (e.g. /sɪgnəl/ → [sɪŋgəl]).

This constraint subsumes I-CONTIGUITY ("No skipping"), O-CONTIGUITY ("No intrusion"), and LINEARITY ("No metathesis") from McCarthy and Prince (1995). Bernhardt and Stemberger argue that a separate constraint governing linear order is not necessary, since any re-ordering of segments typically entails a change in contiguity of one segment with another. They acknowledge, however, that metathesis in a word with only two segments (e.g. *up* /ʌp/ → [pʌ]) would not violate **Contiguity** (Bernhardt and Stemberger 1998: 184) since the vowel and the consonant remain contiguous regardless of ordering. They briefly suggest that an **Anchoring** constraint could be used to rule this out. However, they do not define or make use of this constraint in their subsequent analyses, possibly because metathesis of this sort does not actually occur.

More importantly for the present analysis, **Contiguity** fails to rule out the long-distance onset-coda featural metathesis (e.g. /kʌp/ → [pʌk]) found occasionally in Grace's data, as well as in other children. Although the place features of the onset and coda have reversed order, they remain contiguous to the vowel. Some faithfulness constraint is needed to prohibit such re-ordering. I adopt a version of **Linearity** that applies to features as well as whole segments to serve this purpose, defined in (44).

(44) **Linearity**: The precedence order of elements in the input must be respected in the output.

Note that given this definition, long-distance metathesis actually incurs three separate violations of **Linearity**. That is, given the mapping /*abc*/ → [*cba*], the re-ordering disrupts three different precedence relations: $a < b$, $b < c$, and $a < c$. By contrast, local metathesis (wherein /*ab*/ → [*ba*]) disrupts only one precedence relation, making long-distance metathesis "worse" than local metathesis in terms of **Linearity** violations.

The view of **Survived** constraints presented here obviates the need for a constraint such as UNIFORMITY (McCarthy and Prince 1995), which prohibits a segment in the input from having multiple correspondents in the output. Multiple correspondents are argued for in cases of coalescence (e.g. *spider* [faɪdə]), when an output segment contains features from two different underlying segments. However, it is not necessary to view such a segment as corresponding to two input segments, given that independent **Survived** constraints apply to a segment's timing unit, root node, specified features, and even the links between them. In this view, coalescence involves deletion of a segment in violation of **Survived(C-Root)** and **Survived(C-Place)**. If features from both underlying segments survive in the output, as in preservation of [Labial] and [+continuant] in *spider* [faɪdə], this may be viewed as a violation of **Survived(Link)** for one of the features. That is, instead of remaining linked to the structure of its underlying segment, the feature has been de-linked and linked up to the structure of the surviving segment. Since there is no need to view cluster reduction as involving multiple correspondence of segments, there is no need for a separate constraint prohibiting coalescence.

An additional faithfulness constraint is needed to account for the tendency for anticipatory harmony. All other things being equal, there is a tendency to anticipate and preserve a later feature in the prosodic domain, which can be captured in the constraint defined in (45).

(45) **Priority(Last, X)**: The last element X in the prosodic domain has priority.

Bernhardt and Stemberger (1998) refer to this constraint as **Priority(Right)**, which they consider to be grounded in a recency effect. They also posit an opposing **Priority(Left)** constraint, grounded in a primacy effect, to account for children who prefer perseveratory assimilation. I prefer to avoid the terms "left" and "right" in constraint names since they suggest the placement of written segments on the page, a consideration that is not relevant for speech planning. I also differ in my view of the grounding of **Priority(Last)**, which I consider to reflect the fact that good speech planning is by nature forward-looking. As observed in Dell et al. (1997: 123), "when the language-production system is working well, it looks to the future and does not dwell on the past." This explains the fact that the feature of an anticipated segment often dominates in cases of assimilation, not only in child speech, but also in speech errors and in long-distance consonant agreement in adult speech (Hansson 2001, Rose and Walker 2004). I do not make use of a **Priority(Left)** type constraint, since there are very few examples in the literature of strictly perseveratory assimilation, which appears to be limited to very early development or the speech of children with phonological disorders.[42] Hansson (2001) similarly observes that perseveratory speech errors in adults are associated with dysfunctional states of speech production such as aphasic speech or increased speech rates.

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[42] I speculate that while some children may have early perseveratory tendencies, they must learn to anticipate in order to develop good speech planning skills. Such a shift might be correlated with more general cognitive development allowing the child to look ahead to future events.

Bernhardt and Stemberger (1998) posit two additional faithfulness constraint families that I do not find a use for. The first pertains to the linking up of elements in the surface representation of a segment, defined in (46).

(46) **LinkedUpwards**: An element must be linked to an element on the tier above it.

The stated rationale for this constraint is that all elements of a segment must be anchored in time relative to other elements in order to be pronounced. Positing such a constraint allows for a distinction between elements that are deleted and those that are merely de-linked or floating. This permits a way of deriving non-minimal repairs, in which an ill-formed segment is deleted altogether rather than only the offending feature (Bernhardt and Stemberger 1998: 167). This is accomplished by ranking **Survived** and **LinkedUpwards** for the offending feature above **LinkedUpwards(Root)**, allowing the feature itself to "survive" even though the root node is de-linked in violation of lower-ranked **LinkedUpwards(Root)**. However, there is no phonetic difference between a feature that is deleted and one that is floating; in either case, it is not pronounced. Rather than rely on an abstract distinction between deleted and floating features, I dispense with this constraint. Instead, I assume that if an underlying element is not pronounced, this incurs a violation of **Survived** for that element. In 5.2.3, I show that non-minimal repairs can be derived by relying on the distinction between **Survived** and **Identical** constraints discussed above.

Bernhardt and Stemberger (1998) also posit the constraint in (47) to enforce the presence of structure below a given node in the feature hierarchy.

(47) **LinkedDownwards:** Elements must be linked to an element on the appropriate lower tier.

Along with **Survived** for the feature nodes C-Root and C-Place, the **LinkedDownwards** constraint is used to ensure that an underspecified consonant surfaces with all of the features necessary for pronunciation. For example, **Survived(C-Place)** demands that there be a Place node for underspecified /t/, while **LinkedDownwards(C-Place)** demands that some feature be linked up to this Place node, forcing the default place feature [Coronal] to be inserted in violation of low-ranked **Not(Coronal)**. This prevents substitution by a glottal segment, a function served in other analyses by a HAVEPLACE constraint requiring that a segment have some place feature (e.g. Padgett 1995, Parker 2001).[43] However, it seems that this constraint's function can be incorporated into the **Survived** constraint for a feature node if we assume that a node can only "survive" if there is an actual pronounceable feature associated with it. With this interpretation, **Survived(Place)** alone is sufficient to require that a consonant have some place feature, and as a result, I do not make use of the **LinkedDownwards** constraint family.

To summarize, the faithfulness constraint set adopted for the present analysis differs in several ways from the faithfulness constraints typically used in standard OT analyses. Following Bernhardt and Stemberger (1998), I use **Survived** (cf. MAX, not IDENT) constraints for underlyingly specified elements, including the C-Root node, Place node, contrastive non-default features, and the links between features. **Contiguity** is violated by word-internal deletion or epenthesis as well as most cases of metathesis. **Linearity** mandates that the precedence order of elements in the input be respected in the output. A **Priority(Last, X)** constraint, unique to the Bernhardt and Stemberger (1998) model, is also required to capture the priority given in speech planning to survival of the last feature of a prosodic domain. Finally, in a departure from Bernhardt and Stemberger (1998), I dispense with **LinkedUpwards** and **LinkedDownwards** constraints and propose a specific role for **Identical(F)** in evaluating possible substitutes for a given segment to non-default features. Unlike **Survived**, **Identical(F)** constraints can apply to non-default features that are predictable from another contrastive feature specified in the underlying representation and are not violated by deletion.

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[43] A difference between **Survived(C-Place)** and HAVEPLACE constraint is that the former is a faithfulness constraint, while the latter is a markedness constraint. **Survived(Place)** ensures that an underlying place feature node will be preserved in the output, while HAVEPLACE penalizes any consonantn in the output without a place feature, including underlying glottals. However, the fact that glottals are a common epenthetic onset suggests that the lack of a place feature does not necessarily make placeless consonants less optimal.

2.2.6 The initial state and re-ranking of constraints

In constraint-based models, the learning process is modeled by the re-ranking of faithfulness constraints. The standard view in OT has been that in the initial state of the grammar, all output (a.k.a. markedness) constraints are ranked above faithfulness constraints, abbreviated M >> F (e.g. Prince and Smolensky 2000, Gnanadesikan 1995/2004, Hayes 2004). This initial ranking is intuitive to the extent that it reflects the fact that children's earliest structures are unmarked and many early pronunciations are notoriously unfaithful to the adult target.

The usual assumption is that this initial ranking must be innately built into the system. The alternative advocated by Bernhardt and Stemberger (1998) is that faithfulness begins low-ranked and markedness highly ranked because all phonological skills are learned. Since children must learn how to coordinate all articulatory gestures, production constraints will be tend to be highly ranked initially; by the same token, since children must learn the importance of faithfully reproducing the features of underlying segments in order to preserve lexical contrasts, faithfulness constraints will tend to be low ranked. As Bernhardt and Stemberger point out, it is not generally the case that *all* production constraints outrank faithfulness at the onset of meaningful speech; some faithfulness constraints must be highly ranked if the child is producing recognizable words.

Within OT, two views of the progression of learning have been proposed. Gnanadesikan (1995/2004) suggests that learning proceeds via the promotion of faithfulness constraints. Tesar and Smolensky (2000) argue that learning must proceed exclusively via the demotion of markedness constraints, in order to support an error-driven learning algorithm that will otherwise fail to arrive at the adult ranking (see also Hayes 2004).[44] Stemberger and Bernhardt (1999) argue based on developmental data that constraint demotion cannot be the only learning mechanism. Adopting an exclusive principle of

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[44] Boersma's Gradual Constraint-Ranking Learning Algorithm characterizes the learning process as involving both demotion of markedness and promotion of faithfulness constraints (e.g. Boersma and Levelt 2000).

constraint demotion seems not to allow for certain types of regressions found in actual children acquiring human languages.[45]

A regression is a change in the child's grammar that leads to some aspect of pronunciation becoming less faithful to the adult form, typically as a trade-off for some other aspect becoming closer to the adult target. Stemberger and Bernhardt (1999) distinguish between two types of regression commonly seen in child phonology: correlated and independent. A correlated regression is one that co-occurs with another change in the system, while an independent regression takes place independent of any other change. Amahl's cluster reduction patterns (Smith 1973) provide an example of a correlated regression. Prior to acquisition of fricatives, /st/ onsets are reduced to [t] as in *star* [ta]. After fricatives are acquired, however, the /s/ is preserved instead as in *star* [sa]. This constitutes a trade-off with respect to faithfulness: the new pronunciation is less faithful to the stop, but more faithful to the fricative. This type of regression can easily be explained by the demotion of a constraint against fricatives such as **NotCo-occurring(-sonorant,+continuant)**) below **Survived(+continuant)**, permitting the acquisition of fricatives and simultaneously favoring preservation of the /s/ in /s/+stop clusters.

Accounting for independent regressions via constraint demotion is more problematic. This can be illustrated with an independent regression that occurred in Grace's phonological development with respect to the realization of final voiced obstruents. In her early phonology, the voicing contrast in final obstruents was neutralized via final devoicing. At age 1;11, however, vowel epenthesis with voicing preservation suddenly appeared in words with an underlying final voiced stop, such as *read* [widə] and *flag* [ɸwægə]. The regression is illustrated in (48).[46]

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[45] Magri (2009) also argues that constraint promotion is necessary to model the early stage of phonological acquisition, but for different reasons.

[46] Vowel epenthesis as a means of preserving voicing in word-final stops seems to be rare, but is reported for Carolyn (Bernhardt and Stemberger 1998: 427).

(48) Independent regression in Grace’s phonological acquisition

bag	[bɛk] (1;9)	[bɛgə] (1;11)
bug	[bʌk] (1;9)	[bʌgə] (1;11)

This is a trade-off regression, in which faithfulness to voicing occurs at the expense of faithfulness to the number of syllables. Importantly, this regression occurred independently of any other changes in her phonological system. There was no highly ranked production constraint prohibiting CVCV words with intervocalic stop voicing, since Grace already produced words such as *baby* [bibi] and *bagel* [beɪgoʊ]. What, then, could motivate the change? Assuming that the relevant constraints include a constraint prohibiting obstruent voicing in codas (**NotCo-occurring(Coda,-sonorant,+voice)**, a constraint against inserting a vowel (**Not(V-Root)**), and **Survived(+voice)**, they must initially be ranked as in (49):

(49) Constraint rankings for final devoicing

Input: *bug* /bʌg/	[bʌg]	[bʌgə]	[bʌk]
NotCo-occurring(Coda,-sonorant,+voice)	*!		
Not(V-Root)		*!	
Survived(+voice)			*

Subsequently, voiced obstruents remain unviable in codas, so the constraint originally responsible for the devoicing must remain highly ranked. Clearly, the voicing faithfulness constraint has been re-ranked, selecting vowel epenthesis as optimal:

(50) Constraint rankings for voicing preservation via vowel epenthesis

Input: *bug* /bʌg/	[bʌg]	[bʌgə]	[bʌk]
NotCo-occurring(Coda,-sonorant,+voice)	*!		
Survived(+voice)			*!
Not(V-Root)		*	

In an error-driven learning system, there is no apparent motivation for demotion of the constraint against vowel insertion, since a) this risks creating unnecessary epenthesis elsewhere, and b) the error fundamentally results from the constraint against voiced obstruents being ranked too high. There is, however, motivation for promotion of the voicing faithfulness constraint: namely, learning that preservation of English stop voicing is important in all contexts, combined with the knowledge that stop voicing can be preserved in syllable onsets. This type of learning seems to be best reflected in the promotion of a faithfulness constraint (in this case **Survived(+voice)**), indicating that the child has learned to place a higher priority on faithfulness. The demotion of a production constraint, by contrast, would correspond to a change in the child's productive capabilities, which is not the case in this example.

Bernhardt and Stemberger suggest that most learning may in fact take place via promotion of constraints. While demotion of a highly ranked output constraint appropriately models overcoming a production limitation, promotion seems better suited to modeling certain aspects of the learning process, such as placing a higher priority on aspects of faithfulness. It is logical that both types of learning would occur, since children must learn both production routines for various outputs and the importance of featural faithfulness. In the analysis that follows, I will at times remain neutral as to the type of re-ranking that occurs, but in my analysis of Grace's longitudinal data related to initial consonant deletion, I find evidence for both demotion of output constraints and promotion of faithfulness constraints, and conclude that both are necessary in a comprehensive model of phonological acquisition.

With this basic understanding of the constraints and advantages of the Bernhardt and Stemberger (1998) variant of OT, I proceed to an analysis of Grace's acquisition data.

3 Consonant harmony and long-distance metathesis

"…studies of child-speech in such languages as English, French, German, Russian, Italian, Danish, Swedish, Magyar, Calmuck, New Greek, and Finnish, have seemed to afford abundant justification [for the conclusion that there are] in the more prominent mistakes of child pronunciation, tendencies to error in certain common directions such as clearly implied some law as their inciting cause."

--Edmund Noble, *Child Speech and the Law of Mispronunciation*, 1888: 44[47]

3.1 Literature review

3.1.1 Consonant harmony in acquisition

Consonant harmony (CH), or long-distance assimilation of consonant features, is a common process in early phonological acquisition (Vihman 1978, Locke 1983, Bernhardt and Stemberger 1998). Typical examples are given in (46), illustrating the spreading of major place features from one consonant to another across an intervening vowel.

(46) Examples of consonant harmony involving place assimilation (Smith 1973)

__g__ood [gʊg] *duc__k__* [gʌk] *__b__oat* [boʊp]

Sometimes thought to be a universal in child language (Smith 1973: 20), CH is attested in a wide variety of languages, including English (e.g Menn 1971, Smith 1973, Compton and Streeter 1977, Cruttenden 1978, Stoel-Gammon and Dunn 1985, Donahue 1986, Matthei 1989), German (Berg 1992), Dutch (Levelt 1994), Spanish (Macken 1978) and Greek (Drachman 1973a: 148), as well as Chinese, Czech, Estonian, and Slovenian (Vihman 1978). Yet unlike many processes in child speech such as coda deletion and final devoicing, CH of major place features is conspicuously absent in adult language (see Vihman 1978, Hansson 2001, Pater 2002, Rose and Walker 2004). A satisfactory

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[47] Cited in Locke (1983: 62-63).

analysis of CH should ideally account for how children proceed from an early grammar in which harmony dominates to an adult-like grammar in which it plays only a minor role, if any. Arriving at such an analysis begins with a thorough understanding of CH processes in both child and adult language.

Vihman (1978) makes a useful distinction between cases of pseudo-harmony and true harmony. For example, *sat* [tæt] or *kitty* [titi] may appear to be cases of manner and place harmony, but if the child exhibits fricative stopping and velar fronting in all contexts, e.g. *see* [tiː] and *key* [tiː], these are simple cases of context-free substitution. Even excluding such cases, in a cross-linguistic survey of diary studies from thirteen children ages one to three, Vihman (1978) found examples of harmony in every child's speech, although its incidence varied greatly, ranging from a high of 32% of forms in an English-acquiring child (Smith 1973), to a low of 1% by a Chinese-acquiring subject (Clumeck, unpublished data cited in Vihman 1978).[48] Since the studies cited in Vihman (1978) did not constitute a random sample, however, we cannot conclude that all children use CH. A longitudinal study of early phonological development in 33 normally-developing English-acquiring children reported labial harmony in 10 children and velar harmony in 10 children (Stoel-Gammon and Stemberger 1994), indicating that CH is not universal.[49]

Both place and manner features may be involved in harmony. Complete agreement of all consonant features, e.g. *pin* [mɪm], is said to be "characteristic of very early speech" (Smith 1973: 164). Indeed, an initial stage in which all consonants within a word agree in place and manner is evident in a number of subjects for whom data collection begins with first meaningful utterances, including children acquiring English (Ferguson et al.

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[48] Vihman attributes the low incidence of CH in Chinese-acquiring children partly to the fact that relatively few Chinese words in the adult input present a possible consonant contrast, given the large number of monosyllabic words without codas. Vihman also observes that final nasals, the only possible codas in Chinese, are often deleted in child-directed speech.

[49] It is not clear how much overlap there was between the children with labial harmony and those with velar harmony, but clearly CH was not present in all children during the period of the study. Since the data was recorded at three-month intervals, it is possible that CH was temporarily present in additional children, but not at the time of recording.

1973, Compton and Streeter 1977, Matthei 1989), Dutch (Fikkert and Levelt 2008), Estonian (Vihman 1976), Finnish (Vihman and Velleman 2000), Spanish (Macken 1978), and Italian (Keren-Portnoy et al. 2009). However, CH often affects only one feature, as in nasal harmony in *pin* [mɪn]. Less common types of harmony include lateral harmony as in *yellow* [lɛluː] (Smith 1973) or Italian *cavallo* [kalolːo] (Keren-Portnoy et al. 2009) and fricative harmony as in *Lizzy* [zɪzi] (Bernhardt and Stemberger 1998: 558) or Spanish *taza* 'cup' [sasa] (Macken 1978). Most frequently, CH affects place features (Smith 1973, Vihman 1978, Stoel-Gammon and Stemberger 1994). I focus on place harmony since it is the most common type of CH and because a variety of intriguing patterns in phonological development have been reported across children.

It is generally agreed that coronal consonants are the most common undergoers of CH (Vihman 1978, Grunwell 1982, Stoel-Gammon and Stemberger 1994), frequently ceding place of articulation to both labials and velars. This is attested in a wide variety of languages, as exemplified in (47), where coronals undergoing harmony are bolded.

(47) Cross-linguistic examples of coronal undergoers in CH

a. English (Amahl, Smith 1973):

d**uck* [**g**ʌk] *goo**d [gʊ**g**]

*k**n**ife* [**m**aip] *s**n**ake* [**ŋ**eik]

b. Dutch (Jarmo, Fikkert 1994)

/**t**ɑfel/ [**p**afy] 'table' /**z**ep/ [**f**ɪp] 'soap'

c. Spanish (Macken 1978):

/pa**n**/ [pa**m**] 'bread' /**t**roka/ [**k**okg̥a]

d. Czech ("Jiri," Pacesova 1968, cited in Vihman 1978):

/**s**ova/ [**f**ofa] 'owl' /**ʒ**aba/ [baːba] ~ [waːba] 'frog'

e. Estonian (Virve, Vihman 1978):

/pa**t**i/ [pa**p**i] 'pillow' /**t**upa/ [**p**upa] 'room'

/**se**ːpː/ 'soap' [**fe**ːp] /**t**eki/ 'did (it)' [**k**eki]

f. German (Jakobson 1968: 54):

*Gu**t**en **T**ag, Herr **D**oktor* "Guken **G**ag Herr **G**oka"

There has been disagreement regarding the harmony bias when labials and velars co-occur within a word. Based on data from different English-acquiring children, there have been contrary claims that velars assimilate to labials as in *piggy* [pɪpi] (Cruttenden 1978) or that labials assimilate to velars, e.g. *big* [gɪg] (Menn 1975). A larger study of English-acquiring children found no statistically significant pattern in this respect (Stoel-Gammon and Stemberger 1994). Macken (1996), however, claims that assimilation of velars to labials is less common than the reverse.

In terms of directionality, harmony can be perseveratory (sometimes called progressive) or anticipatory (sometimes called regressive). Perseveratory or progressive harmony occurs when a place feature spreads to a following consonant as in *good* [gʊg]. Anticipatory or regressive harmony occurs when a place feature spreads to a preceding consonant as in *duck* [gʌk]. I will use the terms perseveratory and anticipatory to refer to directionality, since these terms are more transparent.

Macken (1996) notes that CH is initially bidirectional in phonological development but that anticipatory harmony persists longer, especially when coronals precede the labial or velar trigger. She suggests an onset-coda asymmetry for harmony triggers in CVC words, claiming that velars (with dorsal place) in codas are particularly strong harmony triggers, while labials dominate word-initially (at least in English), as reflected in (48):

(48) Hierarchies for harmony triggers in CVC words (Macken 1996)
    a. Onsets: Labial >> Dorsal >> Coronal
    b. Codas: Dorsal >> Labial >> Coronal

However, no examples are given, making this claim difficult to evaluate.[50] For a labial onset followed by a velar as in *book*, the implication is not clear, since according to her hierarchy, both the labial onset and the velar coda should be strong harmony triggers, but they cannot simultaneously trigger harmony over each other. Anticipatory velar harmony with a labial onset as in *book* [gʊk] is attested in several studies (Menn 1971;

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[50] Macken (1996) refers the reader to a paper to appear in the *LabPhon V* proceedings for further details; however the cited article did not appear in the published proceedings.

Stoel-Gammon and Dunn 1985; Pater 2002) The hierarchy for codas implies that anticipatory harmony is likely to be triggered by a dorsal coda, especially when preceded by a coronal as in *duck* [gʌk], a tendency confirmed in Grunwell (1982: 172) and Stoel-Gammon (1996), who finds that for English-acquiring children, the presence of perseveratory velar harmony implies anticipatory velar harmony. In a velar + labial sequence as in *cup*, neither the initial velar nor the labial coda is a strong harmony trigger, so the implication seems to be that this sequence is not likely to undergo harmony. My review of the literature indicates that harmony of this sequence is indeed rare (but cf. Trevor, Pater 1997; Molly, Vihman and Velleman 1989).

Pater (2002), building on other studies of CH, articulates the implicational generalizations in (49).

(49) Consonant harmony implicational generalizations (Pater 2002)
  a. Undergoer: Non-Coronal implies Coronal
  b. Trigger: Labial implies Velar
  c. Direction: Perseveratory implies Anticipatory

Pater (2002) illustrates these tendencies using longitudinal data from two English-acquiring children, Trevor (Compton and Streeter 1977, Pater 1997) and Amahl (Smith 1973). The generalization in (49)a means that if non-coronal consonants undergo harmony within a child's grammar, as in assimilation of the labial to the velar in *book* [gʊk], it is the case that coronal consonants also undergo harmony, as in *boat* [boʊp]. The generalization in (b) states that if labials trigger harmony, velars do also, while the reverse is not true. That is, a child with labial harmony as in *boat* [boʊt] should also have velar harmony as in *coat* [koʊk], but a child may exhibit velar harmony without labial harmony being attested.[51] Finally, the generalization in (c) states that a child with perseveratory harmony will also have anticipatory harmony but not vice versa, essentially confirming Macken's statement that anticipatory harmony persists longer. The dominance of velar and anticipatory harmony is also documented for English-

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[51] This claim is contradicted by data from several studies in which labial harmony occurs without velar harmony, discussed further in 4.1.3.

acquiring children with phonological disorders, who tend to exhibit the error patterns of much younger typically developing children (Leonard et al. 1980).

Although the scope of CH in child language is fairly well understood, an understanding of its motivation is somewhat elusive. Vihman observes that "clearly no simple notion of 'ease of articulation' will greatly advance our understanding of the phenomenon" (Vihman 1978: 321), but suggests that harmony "simplifies the child's mnemonic problems in recording and storing a rapidly growing lexicon (Vihman 1978: 328). However, this seems to assume that the forms are stored in the lexicon in their harmonic forms, an assumption that would not be consistent with the evidence that children have accurate perception and adult-like underlying representations, as discussed in 2.1.

Vihman (1978) also suggests that harmony may also serve as a strategy for dealing with "difficult" (late-acquired) consonants. This role is similarly advocated for CH in children with phonological disorders (Leonard et al. 1980). Difficulty with particular segments may indeed be a factor in some instances; for example, in the latter study, perseveratory labial harmony was rare but attested in *pillow* [pɪbo], where avoidance of typically late-acquired [l] may be relevant.[52] In the same study, a frequently harmonized word across subjects was *chick* [kɪk], which may be related to the difficulty posed by an initial affricate. However, it is clear that late-acquired segments are not the only targets, given that oral stops are often subject to harmony despite being the earliest acquired consonant type. In Grace's data, for example, the minimal pair *kitchen* [tɕɪtɕən] and *chicken* [kɪkɛn] demonstrates that both the stop and the affricate were possible in syllable onsets, yet both were targets of harmony. The features of a given segment are therefore insufficient to explain which segments undergo harmony; rather, harmony is dependent on the particular sequence of target consonants involved.

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[52] Interestingly, the one instance of consonant harmony I recall from my own childhood was also *pillow* as [pɪboʊ], a favorite pronunciation I continued to use (e.g. when emulating "baby talk") long after I could pronounce *pillow* accurately.

Vihman (1978) also proposes that CH may allow the child to advance in some other aspect of acquisition by reducing the complexity of words. Menn (1974: 3) suggests that it serves to increase "the redundancy of the articulatory instructions necessary to produce the child's forms." Cruttenden (1978: 378) hypothesizes that CH results from a kind of "inadequate planning of the timing of the various articulations involved." In the context of Evolutionary Phonology, Blevins (2004: 228) views CH in child speech as a form of articulatory simplification "used to avoid difficult sounds or sound sequences." Bernhardt and Stemberger (1998) similarly argue that harmony in child speech is a way of dealing with difficult consonant sequences, a view that is consistent with the evidence presented thus far, and one that I adopt here.

While CH involving major place features is common in child speech, it is not attested in adult languages (Hansson 2001, Rose and Walker 2004), where long-distance consonant agreement typically involves assimilation of minor dependent features, often in a sequence of segments that are already very similar (such as two coronal stops or fricatives). The most common type of CH in adult languages is sibilant harmony, producing [s]~[ʃ] alternations (Vihman 1978, Rose and Walker 2004), attested in a variety of languages such as Basque, Tashlhiyt Berber, Moroccan Arabic, and many Athapaskan languages. In their thorough overview of consonant agreement, Rose and Walker (2004) classify sibilant harmony as one of three different types of coronal agreement, the others being retroflex and dental agreement (in languages with an alveolar/dental distinction). Dorsal agreement is also attested in languages with a velar/uvular stop contrast. Other features that may be involved in long-distance assimilation include nasality, liquid features (lateral/rhotic agreement), and laryngeal features (Rose and Walker 2004). Long-distance agreement of stricture features, which is also rare in children, is essentially nonexistent in adult language.[53] Typical examples of CH in mature languages are given in (50):

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[53] Rose and Walker (2004: 484) discuss a possible counterexample to this generalization and conclude that it is a special case of coronal agreement.

(50) Consonant harmony in adult languages (as cited in Rose and Walker 2004)

a. Sibilant (Coronal) harmony in Aari suffix /-**sis**/ (Hayward 1990)
giʔ-**sis** 'cause to hit'   but: naʃ-**ʃiʃ** 'cause to like'

b. Retroflexion agreement in Gimira causative affix /**s**/ (Breeze 1990)
mak 'say'   ma**s** 'cause to say'
z̢ert 'be red'   z̢er**ʂ** 'make red'

c. Dorsal agreement in Tlachichilco Tepehua prefix /**ʔuks**-/ (Watters 1988)
ʔuks-k'atsaː 'feel, experience sensation'
but: **ʔoqs**-laqts'-in 'look at Y across surface'

d. Nasal agreement in Ndonga suffixal /-**l**/ (Viljoen 1973)
pep-**el**-a 'blow towards'   but: kun-**in**-a 'sow for' surface'

e. Liquid agreement in Bukusu benefactive suffix /-**ila**/ (Odden 1994)
lim-**ila** 'cultivate for'   but: kar-**ira** 'twist'

Harmony in fully developed languages is often stem-controlled, as in all of the above examples, where a feature in an affix assimilates to a feature in the stem. When not stem-controlled, however, CH is consistently anticipatory (Hansson 2001), mirroring the tendency for anticipatory harmony in children. An example is given in (51), where the Rwanda causative suffix /iːʃ/ triggers harmony in a preceding root.

(51) Anticipatory harmony in Rwanda (Kimenyi 1979, cited in Hansson 2001)
/ku-saːz-iːʃ-a/ [guʃaːʒiːʃa] 'cause to grow old'

Various analyses of CH have been proposed. In rule-based approaches, a long list of specific rules changing one place of articulation to another in various contexts is necessary to account for a child's harmony patterns (e.g. Menn 1971, Ferguson et al. 1973). Constraint-based analyses have the advantage of deriving a variety of attested patterns by various rankings of a small set of constraints. The specific constraints used to motivate CH in child language vary, ranging from constraints preferring the alignment of certain place features with a particular word edge (Vellemann 1996, Goad 1997, Dinnsen and O'Connor 2001) to harmony-specific agreement constraints (Pater 2002, Pater and Werle 2003). However, missing from these accounts is a principled explanation for the various harmony tendencies outlined above as well as the similarities and differences in CH as attested in child and adult language. Bernhardt and Stemberger (1998) are unique in presenting an account of CH as a response to constraints on consonant feature sequences, constraints that remain active on certain levels in the adult language. This is the view I develop in this paper.

While CH patterns are often examined in isolation, they are best understood in the broader context of the child's acquisition of consonant feature sequences (see also Fikkert and Levelt 2008 for a view of CH couched in the child's acquisition of place features). Under this view, a child's consonant metathesis patterns are also relevant for understanding the acquisition of consonant sequences. An overview of metathesis in phonological acquisition is therefore in order before proceeding to a detailed account of the harmony and metathesis patterns in Grace's phonological development.

3.1.2 Long-distance consonant metathesis in acquisition

While not as prevalent as harmony, metathesis is another process in child phonology that affects major place features on non-adjacent consonants, such as the onset-coda metathesis in *cup* [pʌk]. Like harmony, long-distance metathesis of major place features is unattested in adult languages, where metathesis overwhelmingly involves immediately adjacent segments (Ultan 1978, Velleman 1996, Hume 2004).[54] While Bernhardt and Stemberger (1998) consider metathesis to be the least common type of repair children make use of (after deletion, default insertion, spreading, and epenthesis), there are nevertheless multiple reports of long-distance metathesis in early phonological development in a variety of languages, including English (Smith 1973, Compton and Streeter 1977, Ingram 1974, Jaeger 1997, Bernhardt and Stemberger 1998, Brulard and Carr 2003), Spanish (Macken 1978, Macken 1979), Greek (Drachman 1973a), French (Grammont 1916, Rose and dos Santos 2006), and in a Hebrew-English bilingual child (Berman 1977).

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[54] The few examples of noncontiguous metathesis available appear to involve historical metathesis of liquids; e.g. Contemporary Spanish *palabra* from older *parabla* (Ultan 1978). The fact that these segments differ only in laterality may contribute to their susceptibility to metathesis, as only one feature is affected in the re-ordering.

Macken characterizes metathesis as an uncommon process that occurred for her subject Si only in those words that "contained labial and dental consonants in the 'wrong' order" (Macken 1979: 28), according to the child's preference for the labial consonant to appear first. While metathesis was uncommon in Si's data, the preference for an initial labial is not uncommon across children. Ingram (1974) proposes a possible universal preference for "fronting," a process in which children prefer more front consonants to appear first in a sequence (i.e. labial before coronal or velar; coronal before velar). An example of fronting occurs in the common childhood mispronunciation of *animal* as [æmɪnəl], which involves metathesis of a coronal + labial sequence. Velar + labial sequences seem particularly vulnerable to metathesis, being reported in multiple studies (Ingram 1974, Compton and Streeter 1977, Jaeger 1997, Brulard and Carr 2003). Examples of labial-first metathesis are cited in (52)(a)-(c).

(52) Metathesis illustrating labial-first preference

a. Metathesis of velar + labial, various languages

English: *gumby* [baŋgi] *coffee* [baki][55] (Philip, Ingram 1974)

Spanish: *cama* 'bedroom' [mœ̃kːə̃] ("J," Macken 1978)

Estonian: /ma**k**a**p**/ 'is sleeping' [ma**m**a**k**] (Virve, Vihman 1978)

b. Metathesis of velar + labial stops in *cup* (Ingram 1974, others):

John-Charles: *cup* [pak] Jennika: *cup* [bək] Kristen: *cup* [bək]

Alice: *cup* [pʌkʰ] (Jaeger 1997)

Tom: *cup* [pɔk] (Brulard and Carr 2003)

c. Metathesis of coronal + labial

Philip: *animal* [mænu] (Ingram 1974)

Alice: *TV* [piti] (Jaeger 1997)

Si: *sopa* [pota] *libro* [pito] (Macken 1979)

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[55] This example illustrates that metathesis may involve place features only. In the analysis of metathesis that follows, I assume the most minimal linearity violation possible, i.e. metathesis of place features rather than entire segments.

Metathesis not involving a labial articulation (i.e. metathesis of lingual sequences) is occasionally reported. Macken (1979) reports one such word that briefly exhibited metathesis in Si's vocabulary: *gato* as [tako]. Two other studies of subjects with fronting metathesis in labial sequences also include examples of lingual metathesis, as in (53).

(53) Metathesis of velar + coronal sequences

a. *candy* [naŋi] (Philip, Ingram 1974)

b. *kite* [taʲkʰ] *kitty* [tiki] ~ [kiki] (Alice, Jaeger 1997)

While Ingram's original claim was that children would more easily acquire words that respect this fronting pattern, Menn (1975) notes that her son Daniel exhibited the opposite order of acquisition, acquiring velar + labial sequences first (as in *cup*) while labial + velar sequences (as in *pig* [gɪg]) were subject to velar harmony, a pattern also attested in Trevor (Pater 2002). Cases of non-fronting metathesis have also been reported. For example, Robert, a French-acquiring child, had the opposite tendency in metathesis of target Labial…Dorsal sequences, as in *beaucoup* [kɔpu] and *paquet* [kape] (Grammont 1916). Amahl (Smith 1973) also had a brief stage where metathesis occurred to create dorsal-initial sequences, producing words such as *icicle* [aikitəl], *whisker* [wiktə], *plastic* [plɑkit], and even *difficult* [gɪpɪtul]. Shelli, a Hebrew-English bilingual child, also had a preference for initial dorsals, using metathesis for both Labial…Dorsal and Coronal…Dorsal target sequences as in (54).

(54) Metathesis preferring initial dorsals (Shelli, Berman 1977)

buggy [gʌbi] *monkey* [kami] *piggie* [kibi]

dog [god] *tunik* [kuni] *Alex* [kali]

A more unusual metathesis pattern involves movement of an initial sibilant to final position, as in *zoo* [uz] and *soap* [ops] produced by "W" (Leonard and McGregor 1991). This type of sibilant metathesis is no doubt related to the fact that fricatives are often acquired first in codas and only later in onsets[56] (e.g. Edwards 1996) and therefore a

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[56] Acquisition of final fricatives before initial fricatives was also a characteristic of Grace's development and is discussed in 5.2.1 as it relates to her consonant deletion patterns.

child may move the highly salient fricative to the coda as a means of preserving the segment. While this type of metathesis is rare, it has something in common with the frequent childhood mispronunciation of *spaghetti* as [pəskɛɾi], where metathesis of initial [s] avoids /s/ in the onset (and also results in a sequence in which the labial precedes the coronal). For purposes of the present analysis, I focus on the more common type of long-distance metathesis involving major place features.

Misperception has sometimes been suggested as a possible underlying cause for long-distance metathesis in children (Berman 1977, Leonard and McGregor 1991). However, such an analysis would be at odds with the considerable evidence that perception precedes production (Eilers and Oller 1976, Swingley 2009, inter alia), including a study showing that even very young infants can discriminate CVC sequences such as [pat] from [tap] (Bertoncini and Mehler 1981).[57] The only other explanation offered for this type of metathesis is the preference noted by Ingram (1974) to produce the more front articulation first within a sequence of consonants, although this is not true of all children, and the underlying reason for this preference is not made clear. A more basic explanation dates back to Grammont (1933, cited in Hume 2004), who states that metathesis is basically a process in which uncommon sequences are replaced by more common ones.

The potential role of frequency in metathesis is discussed in a recent overview of metathesis in adult languages (Hume 2004). In adult speech, metathesis is generally limited to the reordering of immediately adjacent segments, for which Hume claims two conditions must be met. One is that the outcome of metathesis must be a sequence attested in the speaker's language, typically a more frequent sequence than the original one. The second is indeterminacy of the signal with respect to the order of sounds involved, whether due to segments of relatively longer duration with featural cues that may overlap (e.g. glottals, liquids, and glides), or to the lack of sufficient auditory cues

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[57] The infants studied were able to discriminate varying orders of CVC sequences, but not CCC sequences of voiceless obstruents comprising impossible syllables in the adult language, such as [pst] and [tsp] (Bertoncini and Mehler 1981).

for a segment in the given context. Stops, for example, which rely heavily on release burst for place and manner feature cue, are best perceived in pre-vocalic position and may be more susceptible to metathesis when followed by a consonant. Indeterminacy of the acoustic signal does not appear to be relevant for the long-distance metathesis attested in child language, given that the most common case involves the re-ordering of place of articulation between two non-adjacent stops. Metathesis of this nature does not change the structure of the sequence; a Stop-V-Stop sequence remains Stop-V-Stop. I am unaware of any difference in cue perception between pre-vocalic and post-vocalic labial or velar stops that would favor one ordering of place features over the other.

Consonant metathesis in children thus differs in certain ways from metathesis in adult languages. Long-distance consonant metathesis is common in children, but metathesis in adults overwhelmingly involves adjacent segments. Metathesis in adult speech is claimed to depend on indeterminacy of the acoustic signal (Hume 2004), yet this does not appear to be relevant in the type of long-distance place metathesis commonly reported in children. In addition, Mielke and Hume (2001) claim that metathesis of word-initial segments is disfavored in adult speech, yet initial segments often undergo metathesis in early phonological development.

CH and long-distance metathesis have typically been treated separately in the literature on phonological acquisition, with few exceptions (cf. Macken 1992, Velleman 1996, Rose and dos Santos 2006). However, there are several compelling parallels between the two processes. In child speech, both apply primarily to major place features in consonant sequences with an intervening vowel and may affect an initial consonant. Both processes are unattested in adult phonology for major place features. Furthermore, labial and dorsal features dominate in both processes; in harmony, dorsals and labials trigger harmony over coronals, and dorsals and labials are also most likely to participate in long-distance metathesis.

What is the connection between harmony and long-distance metathesis of major place features in child language, and how do these processes emerge and then disappear in the course of phonological development? In order to better understand the role of these processes in a child's grammar, I examine them in the context of my daughter Grace's acquisition of consonant place sequences from age 1;1 to 1;11. Since her harmony and metathesis patterns are in many ways typical, an understanding of their role in her grammar can lead us to a better understanding of these processes in phonological acquisition. When viewed as different responses to constraints on sequences of place features, we find an explanation for the parallels between harmony and metathesis as well as a better understanding of how these processes emerge in acquisition.

3.2 Case study in harmony and metathesis: Grace

3.2.1 Harmony and metathesis patterns in the data

Data transcription began with the production of Grace's first meaningful utterances at age 1;1. The most striking characteristic of her early word production is that up until 1;6, all words in her vocabulary (< 50 words) are limited to a single consonantal place and manner of articulation within a word. This limitation is not uncommon at the onset of meaningful speech, being reported in children acquiring English (Ferguson et al. 1973, Compton and Streeter 1977, Donahue 1986, Matthei 1989), Spanish (Macken 1978), Estonian (Vihman 1976), Dutch (Fikkert and Levelt 2008), and Italian (Keren-Portnoy et al. 2009).

The one place/one manner restriction is respected in Grace's data using three different strategies. The first is simply vocabulary selection, as in (55)a. Lexical selection (or avoidance) is a well-documented strategy whereby children primarily attempt consonants or consonant sequences that they find easy to produce and avoid those they find difficult (Menn 1971, Drachman 1973b, Ferguson et al. 1973, Ferguson and Farwell 1975, Vihman 1978, Macken 1978, Donahue 1986, Matthei 1989, Fikkert and Levelt 2008).[58] The second way that words satisfy this constraint is by deletion of one of the

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[58] Vihman (1978) observes that children's productions begin with a higher percentage of words whose adult target has no consonant contrast; for example, three children's vocabulary at the 50-word stage consisted of 56%, 46%, and 42% of such words, which later decreased to 17%, 24%, and 28% of their total vocabulary respectively (Vihman 1978: 293). Fikkert and Levelt (2008) observe the same early preference in Dutch.

underlying consonants as in (55)b, leaving only one consonantal place of articulation. Finally, some words respect this limitation via CH as in (55)c. As is typical, coronal stops assimilate to a non-coronal place of articulation.

(55) **Grace, age 1;1 - 1;6: one Consonantal Place and Manner**

a) Achieved by vocabulary selection

(ba)nana [nænæ]   *Daddy* [dæi]   *hi* [haɪ]
"boop" [bʊp]   *baby* [bibi]   *bumpy* [bʌpi]
cracker [kækʊ]   *go* [goʊ]   *cook* [kʊk]

b) Achieved by deletion

bread [bɛ]   *bottle* [ba]   *kitty* [kɪi]
milk [ɛʊk]   *juice* [ʊs]   *please* [is]
hat [æt]   *help* [ʌʊp]   *banana* [nænæ][59]

c) Achieved by harmony over coronals (as of 1;6)

coat [kɔk]   *cut* [kʌk]   *boat* [boʊp]

Just as she reaches 1;7, Grace breaks the one place/manner constraint with the addition of *splash* [pas] to her vocabulary.[60] Her first consonant sequences differing in place and manner are all labial-initial, where the second consonant may be coronal or velar, as seen in (56)a. This eliminates perseveratory labial harmony, so that *boat* is now produced faithfully as [boʊt]. In addition, glottal [h] may be followed by any consonantal place of articulation, as shown in (56)b.

(56) **Grace, age 1;7: First sequences acquired**

a) Labial-initial sequences

bug [bʌk]   *bike* [baɪk]   *pig* [pɪk]
boat [boʊt]   *mine* [maɪn]   *mouse* [maʊs]

b) Glottal…Any Place

hot [hat]   *hop* [hap]   *sock* [hak]

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[59] As noted in 1.3.1, Grace deleted initial unstressed syllables throughout her first year of speech.

[60] This is the same consonant sequence as Virve's first word of different place and manner features, the Estonian word [pis] 'pee' (Vihman 1978: 317).

As it turns out, early acquisition of labial-initial sequences is a common developmental pattern, being the first sequence acquired in 21 of 22 studies of early phonological development surveyed in MacNeilage, et al. (2000),[61] as well as two other diary studies of English acquisition (Velten 1943, Vihman and Velleman 1989) and two French-acquiring children (Rose and dos Santos 2006). After acquiring labial-initial words, Labial…Lingual sequences become the most productive pattern in Grace's speech. From age 1;7.1-1;7.30, for example, she acquired 16 new words following this pattern, compared to 26 words representing all other production patterns. Only two of these new words involved consonant harmony, suggesting a continuing tendency to avoid sequences that she found difficult to produce.

Having acquired labial-initial sequences, Grace is able to add another strategy for difficult sequences to those already in use. Instead of harmony or deletion, long-distance metathesis is the preferred repair in the two monosyllabic words she attempts with a target Dorsal…Labial sequence, as in (57)a. While rare in her speech, Dorsal…Labial metathesis is the most frequent metathesis pattern reported across children, as noted above. During this same time period, velar harmony persists over coronals, as illustrated in (57)b.

(57) **Grace, age 1;7-1;8: Velar harmony and metathesis**
  a) Metathesis of Dorsal…Labial sequences preferred
    grape [beɪk]   *cup*[62] [pʌk] (acquired at 1;8)
  b) Persistent velar harmony over coronals (bidirectional)
    cut [kʌk]   *cold* [koʊk]   *doggie* [gagi]   *truck* [kʌk] (at 1;8)

Acquisition of labial-initial sequences eliminates perseveratory labial harmony, but anticipatory labial harmony is still attested in a few words. Although she generally avoids Coronal…Labial sequences, the one French word she attempts at age 1;8 with this

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[61] While the MacNeilage et al. study does not name the exception, the only such example I have come across is Trevor, whose first sequences were apparently Dorsal…Labial (Compton and Streeter 1977, as discussed in Pater and Werle 2003).

[62] The occasional variant *cup* [pʌp] was also attested, but metathesis was the preferred output.

target sequence does undergo labial harmony, as in (58)a. In addition, labial harmony occurs in a few disyllabic Dorsal…Labial sequences, as in (58)b:

(58) **Grace, age 1;8: Anticipatory labial harmony**
  a) Harmony in one attempted Coronal…Labial sequence
    Fr. *un oeuf* /œ̃nøf/ [mœɸ] '(an) egg'[63]
  b) Harmony in disyllabic Dorsal…Labial sequences
    Grandpa [bæpa]   *Grandma* [mæma]

Grace's acquisition of place sequences proceeds rather quickly. At age 1;8, she produces her first Dorsal…Coronal sequence accurately. About two weeks later, she acquires Coronal…Dorsal sequences as well, eliminating most instances of velar harmony.[64]

(59) **Grace, age 1;8: Acquisition of Lingual sequences**
  a) Dorsal…Coronal sequences
    corn [kojn]   *(a)gain* [gɛn]   *goose* [gus]   *kiss* [kɪs]
  b) Coronal…Dorsal sequences (beginning at 1;8.12)
    dog [dak]   *duck* [dʌk]   *knock* [nak]   *stuck* [tʌk]

At 1;9, Grace acquires labial-final sequences, eliminating both metathesis and anticipatory labial harmony.

(60) **Grace, age 1;9: Acquisition of labial-final sequences**
  a) Coronal…Labial: *snap* [næp]   *stop* [tap]
  b) Dorsal…Labial: *cup* [kʌp]   *grape* [geɪp]

However, anticipatory harmony persists in words containing an affricate and a velar stop in sequence, as in (61). Since these consonants all involve a [Dorsal] feature, I refer to this as dorsal harmony.

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[63] Grace substitutes the bilabial fricative [ɸ] for labio-dental /f/ in all contexts until age 2;8.

[64] Although Dorsal…Coronal sequences are acquired prior to Coronal…Dorsal sequences, perseveratory velar harmony persists slightly longer in words with a back vowel, namely *cold* [koʊk] and *coat* [koʊk]. Anticipatory velar harmony is also briefly attested in the expression *bad guy* [gægːaj] at 1;8. These exceptions will be addressed in the analysis below.

(61) **Grace, age 1;9: Persistent anticipatory dorsal harmony**

chicken [kɪkɛn] *kitchen* [tɕɪtɕən]

The minimal pair *chicken/kitchen* clearly shows that anticipatory assimilation is the preferred direction of harmony, regardless of the underlying ordering of stops and affricates; in both cases, an initial consonant assimilates to a following segment. By age 1;11, *kitchen* and *chicken* are produced accurately, eliminating all CH in Grace's speech.

The chart in (62) summarizes Grace's consonant place harmony and metathesis patterns at different stages in her phonological development. Her first words are limited to one place of articulation, with coronals undergoing both labial and velar harmony. At age 1;7, perseveratory labial harmony is eliminated but anticipatory labial harmony is attested. At the same time, metathesis of Dorsal…Labial sequences occurs and bidirectional velar harmony persists for a short time. Subsequently, only anticipatory forms of labial and velar harmony are attested. Finally, only anticipatory dorsal harmony persists in words with affricates and velar stops.

(62) **Feature and directionality patterns in Grace's harmony and metathesis**

(*arrows indicate direction of assimilation*)

Period 1	***Period 2***	***Period 3***	***Period 4***
←Dorsal→	←Dorsal→	←Dorsal	←Dorsal
←Labial→	←Labial	←Labial	(*with affricates*)
	(Dor…Lab metathesis)		

These acquisition patterns reflect the tendencies for harmony undergoers, triggers and directionality highlighted in Pater (2002), and lead to several questions. Why should certain types of place harmony persist longer than others? Why does metathesis emerge briefly in her speech, and only for Dorsal…Labial sequences? More fundamentally, what is the underlying motivation for harmony and metathesis in her development? In the analysis to follow, I argue that we can make sense of these patterns by viewing harmony and metathesis as different responses to constraints on sequences of features. Specifically, I propose that with the addition of a **Lingual** node dominating the Coronal and Dorsal place nodes (as introduced in Section 2.1.2), the interaction of sequence constraints and faithfulness constraints for non-default features provides a logical account of Grace's progression from one stage to the next.

3.2.2 Analysis

As discussed in 2.2.3, the production of place features or feature nodes in sequence is governed by **Agree** and **NoSequence** constraints that reflect the cognitive effort involved in speech planning. **Agree** constraints prohibit a sequence of features or feature nodes with different values (e.g. **Agree(C-Place)**, **Agree(Coronal)**), while **NoSequence** constraints prohibit specific sequences of differing features in a particular order, such as **NoSequence(Dorsal…Labial)** or **NoSequence(Labial…Dorsal)**. I propose that bidirectional CH is motivated by **Agree** constraints applying to each node in the feature hierarchy (i.e. C-Place, Lingual, Dorsal), while **NoSequence** constraints motivate unidirectional harmony or metathesis as specific feature sequences are acquired.

Grace's initial state, in which words are limited to one consonantal place of articulation, may be attributed to a high ranking of the constraint in (63).

(63) **Agree(C-Place)**: Differing specifications of C-Place may not occur in sequence.

When defined over the domain of the prosodic word, the consequence of a high ranking of this constraint would be to limit any given word to one C-Place node, either by vocabulary selection as in *baby* or *go*; by deletion as in *milk* [ɛʊk]; or by harmony. This constraint accurately captures Grace's limitations at 1;6, since placeless [h] was the only consonant to freely co-occur in sequence with another consonant. The role of such a constraint is evident in harmony patterns observed in several other children. Stemberger (1993) notes that glottals were transparent to place feature spreading in Larissa's speech. Macken (1979: 18) reports on a Spanish-acquiring child who freely produced glides while other consonant sequences were subject to harmony, a pattern she attributes to the non-consonantal nature of glides, which are considered to have

V-Place rather than C-Place.[65] Donahue (1986) similarly notes that "vocalic words" where glides were the only consonants escaped the strong consonant harmony rule active in Sean's early grammar. Note that a high ranking of an **Agree(C-Place)** constraint corresponds to a stage in which harmony is of necessity bidirectional, since any two adjacent C-Place nodes with differing place specifications violate the constraint. As indicated above, bidirectional harmony is characteristic of many early grammars.

The question of which place of articulation dominates in CH is left to other constraints. Following the typical pattern, the non-coronal place of articulation is preserved in Grace's speech at the expense of the coronal consonant, e.g. *boat* [boʊp] and *coat* [koʊk]. This is predicted by the Bernhardt and Stemberger (1998) approach to default underspecification outlined in 2.2.5. To review, default feature values are determined by frequency in the input. Since coronal consonants are typically most frequent, [Coronal] typically becomes the default place feature. The fact that default features are easiest to access in speech production is reflected in a low ranking of **Not(Coronal)** with respect to the constraints against non-default place features, as in (64).

(64) Ranking of **Not** constraints for place features (*where Coronal=default*)
Not(Dorsal), Not(Labial)[66] **>> Not(Coronal)**

Recall that the ranking of the faithfulness constraint **Survived(F)** above the corresponding **Not(F)** constraint ensures survival of a constrastive non-default feature. Thus a ranking of **Survived(Dorsal) >> Not(Dorsal)** would permit production of underlying velars. Default features such as [Coronal] do not require a corresponding **Survived** constraint, since in the absence of any other specification, the low ranking of **Not(Coronal)** will ensure that a coronal surfaces, as long as **Survived(C-Place)** is ranked

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[65] Since Grace produced no initial glides at all until 1;11, it is not known how the sequence constraints would have treated glides in her grammar.

[66] As discussed in 2.2.2, Bernhardt and Stemberger (1998) further assume **Not(Dorsal) >> Not(Labial)** in most children (leading to **Survived(Dorsal) >> Survived(Labial)**), but leave room for variation. In the absence of clear evidence of this ranking (e.g. difficulty in velar production), I conservatively assume an equal ranking of constraints against non-default features.

high enough to require a place feature. The ranking schema for **Not** and **Survived** constraints is given in (65), with the highest ranked constraints listed at the top:

(65) Relative ranking of **Not** and **Survived** constraints for place features

Survived(Dorsal), **Survived(Labial)**

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Not(Dorsal), **Not(Labial)**

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Not(Coronal)

The only additional faithfulness constraint I assume for place features is a constraint preserving identity of the [Lingual] feature node, a node introduced in in 2.2.5 that dominates [Dorsal] and [Coronal], reflecting the fact that both are lingual features. Since [Lingual] is entirely predictable from the features [Dorsal] and [Coronal], I posited an **Identical(Lingual)** constraint (rather than **Survived**) to account for context-free substitution patterns in which one lingual consonant substitutes for another. Since [Lingual] is not a non-default place feature, however, I assume that its **Identical** constraint is ranked below the **Survived** constraints for non-default features. With this in mind, the absence of a **Survived** constraint for coronals derives the implication that coronals typically undergo CH, since **Survived(Dorsal)** or **Survived(Labial)** selects preservation of the non-default feature. This is illustrated in (66) for harmony in *boat*.

(66) Non-default place feature preserved over default

Input: *boat* /boʊt/	[boʊt]	[toʊt]	[boʊp]
Agree(C-Place)	*!		
Survived(Labial)		*!	
Not(Labial)	*		*
Identical(Lingual)			*
SinglyLinked(Labial)			*
Not(Coronal)	*	*	

A faithful production of *boat* with its sequence of two different place features is banned in Grace's initial stage by highly ranked **Agree(C-Place)**,[67] and **Survived(Labial)** selects labial harmony over coronal harmony. Note that the spreading of [Labial] place violates **Not(Labial)** and **SinglyLinked(Labial)**, the constraint against doubly linking (or spreading) a feature. In order for harmony to be selected as optimal, **SinglyLinked(Labial)** must be ranked below **Survived(Labial)** and **Agree(C-Place)**.

Just as Grace reaches 1;7, however, she begins producing some sequences of differing place features, indicating that **Agree(C-Place)** is no longer undominated in the constraint hierarchy. The first sequences she acquires are labial-initial consonant sequences, a common trend across children, as discussed in 3.2.1. In order to permit a faithful production of *boat*, **Agree(C-Place)** must now be ranked at least below **Survived(Labial)**, as illustrated in bold in (67).[68]

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[67] Since this constraint is never violated in the initial stage, I assume it is undominated at the top of the hierarchy, although ranking it in the same stratum as **Survived(Labial)** would not change the output in this particular example.

[68] With the inclusion of **Identical(Lingual)** in the constraint set, **Agree(C-Place)** need only be demoted below **Survived(Labial)** to eliminate harmony. Without **Identical(Lingual)**, it would need to be further demoted below **SinglyLinked**.

(67) First sequences acquired

Input: *boat* /boʊt/	[boʊt]	[toʊt]	[boʊp]
Survived(Labial)		*!	
SinglyLinked(Labial)			*
Not(Labial)	*		*
Identical(Lingual)			*!
Agree(C-Place)	*		

With the re-ranking of **Agree(C-Place)**, the relative ranking of **NoSequence** constraints, previously masked, now becomes evident in the consonant sequences possible in her productions. While the trend observed across children in MacNeilage et al. (2000) is for first consonant sequences to consist of Labial…Coronal articulations, Grace's first sequences include labials followed by either coronals or velars, as in *boat* [boʊt] and *book* [boʊk]. If sequence constraints can target the Lingual node introduced in 2.1.2, this pattern is not unexpected. Her first sequences may be characterized as Labial…Lingual, and the fact that the reverse sequence has not yet been acquired points to a highly ranked **NoSequence(Lingual…Labial)** constraint, which prohibits both Coronal…Labial and Dorsal…Labial sequences.

The emergence of long-distance consonant metathesis at this point in her development is explained by this approach. Now that Labial…Lingual sequences are possible, metathesis is a possible output for underlying Lingual…Labial sequences, along with harmony. The ranking of other constraints will determine the preference for one repair over the other. Ultan (1978) observes that metathesis is generally a "conservative" process in that it preserves features that might otherwise be lost in assimilation or deletion. Indeed, metathesis emerges here as a way of preserving both place features in the face of highly ranked **NoSequence(Lingual…Labial)**. Strikingly, it occurs only for Dorsal…Labial sequences and not Coronal…Labial sequences. This is explained by the presence of two non-default place features in a Dorsal…Labial sequence and their corresponding **Survived** constraints. Metathesis is preferred over harmony for a Dorsal…Labial sequence despite the violations of **Linearity** because it satisfies both **Survived(Dorsal)** and **Survived(Labial)**, as shown in (68).[69]

(68) Metathesis in Dorsal…Labial sequences[70]

Input: *cup* /kʌp/	[kʌp]	[kʌk]	[pʌp]	[pʌk]
NoSequence(Lingual…Labial)	*!			
Survived(Labial)		*!		
Survived(Dorsal)			*!	
Linearity				***
SinglyLinked(Place)		*	*	
Agree(C-Place)	*			*

While metathesis is optimal for Dorsal…Labial sequences in monosyllabic words, metathesis never occurs for a Coronal…Labial sequence. A certain degree of avoidance seems to be in effect, since Grace generally does not attempt Coronal…Labial sequences during this time period. However, in the one word she attempts with this target sequence, anticipatory labial harmony occurs, which is predicted by the constraint ranking proposed above. The example in (69) involves one of the few French words in Grace's vocabulary, where her underlying form of *oeuf* 'egg' includes the nasal stop from the preceding indefinite determiner: *un oeuf* /œ̃nøf/ '(an) egg,' produced with labial harmony as [mœɸ].[71]

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[69] As noted in 3.2.1, Grace produced an occasional harmonic form [pʌp] for *cup* at 1;8, indicating a possibly unstable ranking of **Linearity**, which if higher ranked, would make harmony optimal.

[70] Since it is not relevant for this example, I omit **Identical(Lingual)** from this constraint table. In addition, I omit **Not(Labial)** and **Not(Dorsal)** since all candidates incur equal violations for **Not** constraints.

[71] Deletion of the initial unstressed syllable and bilabial fricative substitution are not addressed in the constraint table. As indicated in previous footnotes, Grace consistently deleted initial unstressed syllables (common in English-acquiring children due to trochaic stress preferences), and did not acquire labio-dental fricatives until age 2;8.

(69) Anticipatory harmony in a Coronal…Labial sequence

Input: *(un) oeuf* /nøf/	[nœɸ]	[nœs]	[mœs]	[mœɸ]
NoSequence(Lingual…Labial)	*!			
Survived(Labial)		*!		
SinglyLinked(Labial)				*
Identical(Lingual)				*
Linearity			***!	
Agree(C-Place)			*	

Unlike Dorsal…Labial sequences, **Survived(Dorsal)** does not apply in a Coronal…Labial sequence, and therefore the multiple constraint violations incurred by metathesis select harmony as the optimal output.[72]

Thus the acquisition of Labial…Lingual sequences prior to Lingual…Labial sequences explains the early elimination of perseveratory labial harmony as well as the emergence of metathesis for target Dorsal…Labial sequences only, while anticipatory labial harmony persists in the one Coronal…Labial sequence attempted. An additional characteristic of Grace’s grammar at this time is that velar harmony persists over coronals. Both Dorsal…Coronal and Coronal…Dorsal sequences are still prohibited for several weeks after Labial…Lingual sequences first appear. I attribute this pattern to a high ranking of the **Agree** constraint for the next lower node in the place hierarchy:

(70) **Agree(Lingual)**: Two different lingual articulations may not occur in sequence.

Just as **Agree(C-Place)** prohibited a sequence of differing C-Place features, **Agree(Lingual)** prohibits a sequence of differing lingual places of articulation. This constraint reflects the extra effort inherent in coordinating a sequence of two different

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[72] Rather than violating **Linearity**, the migration of individual place features from one segment to another could be argued to violate **Survived(Link)**. Regardless of the specific constraint violated, however, the number of violations incurred by metathesis makes harmony optimal.

places of articulation that share an articulator; in this case, the tongue. That is, producing a sequence of lingual articulations implies a degree of control in speech planning not required by a Labial…Lingual sequence, which involves two completely independent articulatory gestures. Rose and dos Santos similarly predict that for motoric reasons, sequences of labial and lingual articulations should be easier than sequences of two lingual articulations (2006). This is reflected in the current model. While faithful production of any sequence of differing place requires re-ranking of **Agree(C-Place)**, production of differing lingual sequences also requires re-ranking of **Agree(Lingual)**. As a result, Lingual sequences may be later acquired and thus remain susceptible to persistent velar harmony.[73] The effects of **Agree(Lingual)** remaining highly ranked in Grace's grammar are illustrated in the table in (71), where it forces harmony in a Dorsal…Coronal sequence. Once again, **Survived(Dorsal)** causes the default coronal to cede its place of articulation to the velar.

(71) Persistent velar harmony

Input: *coat* /koʊt/	[koʊt]	[toʊt]	[koʊk]
Agree(Lingual)	*!		
Survived(Dorsal)		*!	
SinglyLinked(Dorsal)			*
Agree(C-Place)	*		

Evidence for the demotion of **Agree(Lingual)** appears at 1;8, when Grace acquires her first Dorsal…Coronal sequences as in *corn* and *kiss*. The relative rankings of **NoSequence** constraints for lingual sequences, previously masked by undominated **Agree(Lingual)**, now become relevant. Since Dorsal…Coronal sequences appear first, a ranking of **NoSequence(Coronal…Dorsal) >> NoSequence(Dorsal…Coronal)** is presumably in effect. The effects of such a ranking are short-lived, however, since she

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[73] Positing this constraint predicts only that lingual sequences are more *likely* to be later acquired, not that there is a strictly enforced order of acquisition. **NoSequence(Lingual…Labial)** may be re-ranked independently of **Agree(Lingual)**, allowing for variation among children.

acquires Coronal…Dorsal sequences less than two weeks later (at 1;8.12) in words such as *dog* and *duck*. Furthermore, she acquires labial-final sequences a few weeks later at 1;9, as in *cup* and *top*, implying re-ranking of **NoSequence(Lingual…Labial)**. These developments eliminate metathesis as well as nearly all instances of harmony.

However, anticipatory harmony persists in *kitchen* [tɕɪtɕən] and *chicken* [kɪkɛn] until as late as 1;11. I attribute this persistent harmony pattern to an **Agree** constraint for the next lower node in the place feature hierarchy, the **Dorsal** node, assuming that her affricate (best transcribed as an alveolo-palatal), had an underlying [Dorsal] feature.[74] The problem in this case is two different [back] specifications under the Dorsal node, i.e. [-back] for [tɕ] and [+back] for [k], creating a sequence of two different [Dorsal] nodes.[75] An **Agree(Dorsal)** constraint may also explain the high frequency of velar harmony in *chick* [kɪk] across children in Leonard, Miller and Brown (1980).

It is significant that regardless of the underlying ordering of the velar and affricate, harmony in this minimal pair is anticipatory. Given that **Survived(Dorsal)** applies to both the velar and the affricate, this constraint cannot determine the direction of harmony as it did for previous instances of velar harmony over coronals. Rather, the decision must fall to another principle. The fact that assimilation is consistently anticipatory in this minimal pair suggests the effects of the faithfulness constraint introduced in 2.2.5 reflecting that in speech planning, anticipation of following segments and features is essential. The constraint giving priority to survival of the last feature of a prosodic domain is repeated in (72).

(72) **Priority(Last, X)**: The last element X in the prosodic domain has priority.

---

[74] Evidence for an underlying [Dorsal] feature in English affricates comes from acquisition data for Daniel, who deleted the initial affricates in *juice* [ufs] and *cheese* [iz] in his early speech, but later substituted a velar stop, producing *juice* [gus] and *cheese* [giz] (Menn 1971: 246). Grace similarly changed her pronunciation of *cheese* [tsis] at 1;5 to [kis] at 1;7. However, given her concurrent pronunciation of *deer* as [gi], I cannot rule out influence of the following vowel.

[75] **Agree(Dorsal)** may also have played a role in velar harmony in *truck* [kʌk] at 1;8, where the initial consonant may be produced as an affricate due to co-articulation effects with the following rhotic. Unfortunately, I did not note when harmony ceased in *truck*, so I cannot comment further.

That is, given a constraint (such as **Agree(Dorsal)**) that forces a choice between preservation of two different elements of a sequence, all other things being equal, **Priority(Last, X)** will favor the second element. Since **Survived(Dorsal)** cannot choose between the two segments, the decision falls to the lower ranked constraint **Priority(Last, C-Place)**, which selects the place node for the second consonant of the sequence, as illustrated in the table in (73).

(73) Anticipatory Dorsal harmony with affricates

Input: *chicken* /tʃɪkən/	[tçɪkɛn]	[tçɪtçɛn]	[kɪkɛn]
Agree(Dorsal)	*!		
Survived(Dorsal)			
SinglyLinked(C-Place)		*	*
Priority(Last,C-Place)		*!	

In this way, the various harmony and metathesis patterns in Grace's phonological development can be understood as resulting from the interaction of faithfulness constraints with both **Agree** and **NoSequence** constraints on consonant place features. The fact that **Agree** constraints apply to each place node in the hierarchy leads to the persistence of certain types of bidirectional harmony. **Agree(C-Place)** initially prohibits any sequence of differing consonant place features. Once it has been demoted, **Agree(Lingual)** causes bidirectional velar harmony over coronals to persist for a short time. Subsequently, even after **Agree(Lingual)** has been demoted, **Agree(Dorsal)** causes persistent anticipatory harmony in sequences of consonants with a dorsal element, namely velars and affricates. This effectively models the finer degree of control in speech planning required to coordinate a sequence of different features that involve the same articulator, explaining why harmony is more likely to affect more similar segments.

The fact that **Survived** constraints apply only to the non-default place features [Labial] and [Dorsal] explains why coronals consistently undergo harmony for prohibited target sequences, as well as the fact that only Dorsal…Labial sequences were subject to metathesis after labial-initial sequences were acquired. Directionality of harmony in this model is determined by a variety of constraints. Highly ranked **Agree** constraints enforce bidirectional harmony over coronals, since they prohibit sequences of differing features regardless of ordering. As **Agree** constraints are demoted, previously masked **NoSequence** constraints can determine the directionality of harmony, depending on which ordering of features is problematic. Finally, all other things being equal, the anticipatory nature of speech planning reflected in **Priority(Last, X)** constraints determines directionality of assimilation.

I now return to a few exceptional cases of harmony in Grace's data. Anticipatory labial harmony occurred somewhat unexpectedly in *Grandpa* [bæpa] and *Grandma* [mæma] instead of metathesis, which applied to target Dorsal…Labial sequences in *grape* [beɪk] and *cup* [pʌk]. The fact that metathesis was selected for target Dorsal…Labial only in monosyllabic words, while harmony was preferred in disyllabic words suggests that the prosodic context is the relevant difference. Rose and dos Santos (2006) also report harmony patterns varying by prosodic context in French acquisition. In Clara's data, for example, CVCV Coronal…Labial sequences are subject to harmony (e.g. *debout* /dəbu/→[bəbu]) but CVC words are realized accurately (e.g. *table* [tab]). Another similar example is reported for a child with velar harmony in *popcorn* [gakon], but not in monosyllabic *big* [bɪk] and only optionally in *block* [bak]~[gak] (Stoel-Gammon and Dunn 1985). It is possible that sequence constraints may be ranked differently for a sequence of onsets, a shared prosodic position, than for an onset-coda sequence.

However, there is another possible explanation for Grace's pattern of harmony in CVCV Dorsal…Labial sequences but metathesis in CVC Dorsal…Labial sequences. As discussed in 2.2.5, onset-coda metathesis in *cup* [pʌk] does not violate **Contiguity** since the two consonants remain contiguous to the vowel, so a **Linearity** constraint was posited to rule out this type of metathesis. Onset-onset metathesis in *Grandpa* [bæka], however, does violate **Contiguity** by disrupting the CV transition in the second syllable. This permits a straightforward way of accounting for the difference. If **Contiguity** is ranked in the same stratum as the **Survived** constraints, it results in harmony being selected over metathesis only in disyllabic words, as shown in (74).

(74) Anticipatory onset-onset labial harmony for Dorsal…Labial sequences

Input: *Grandpa* /gɹæmpa/	[gæpa][76]	[gæka]	[bæka]	[bæpa]
NoSequence(Lingual…Labial)	*!			
Survived(Dorsal)				*
Survived(Labial)		*		
Contiguity[77]			*	
SinglyLinked(Place)		*		*
Priority(Last,C-Place)		*!		
Linearity			**!*	

A similar puzzling aspect of Grace's development is that anticipatory harmony in *kitchen* persisted even after similar sequences in *cage*, *catch*, and *couch* were acquired at 1;9. If different dorsal specifications were possible in an onset-coda sequence, why did harmony still apply in an onset-onset sequence? This points again to the possibility that sequence constraints might be ranked differently depending on the domain of application. A higher ranking for onset-onset sequences would reflect a greater tendency to anticipate features when the consonants are in parallel syllable positions. In this case, **Agree(Dorsal)** may have been ranked higher for onset-onset sequences, explaining why only disyllabic words were problematic. An alternative explanation is that a constraint against repetition of a non-default manner feature within a syllable may be relevant. There was evidence in Grace's initial consonant deletion patterns for a constraint against repetition of [+continuant] within a syllable (see 5.2.2). This constraint could have played a role in ruling out affricate harmony in *catch*, preferring a faithful pronunciation despite the violation of **Agree(Dorsal)**.

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[76] I do not consider candidates with onset clusters, since all clusters were prohibited until 1;11.

[77] This ranking of **Contiguity** is consistent with the cluster reduction patterns discussed in 6.2.2.

Another exceptional case of anticipatory harmony occurs briefly in Grace's data in the expression *bad guy* [gæg:aj] at age 1;8. Harmony in two-word combinations where the two consonants are in parallel syllable positions is attested in other children (Donahue 1986, Matthei 1989). However, harmony in this sequence is unexpected, since Grace had acquired Labial…Lingual sequences in disyllabic words such as *broccoli* [baki] and *monkey* [mʌki]. Again, the prosodic domain of the sequence constraint may be relevant, the difference being that the sequence in *bad guy* involves two stressed foot-initial onsets, while the consonant sequence in *monkey* [mʌki] is foot-internal.

A final exception to address is that although Dorsal…Coronal sequences were acquired prior to Coronal…Dorsal sequences, perseveratory velar harmony persisted slightly longer in Dorsal…Coronal sequences with a back vowel, namely *cold* and *coat*, both pronounced [koʊk]. Pater and Werle (2003) report a similar pattern in Trevor's harmony, noting that while only about 40% of Trevor's KVT words (where K=velar, T=coronal) at age 1;8 underwent velar harmony, nearly 100% of KVT words with back vowels did so (e.g. *coat* [kok]). Stoel-Gammon (1996) also discusses a child who exhibited velar harmony with back vowels only.[78] Consonant-vowel interactions are also reported in data for early Dutch acquisition, where labial consonants tend to co-occur with rounded vowels and velar consonants with back vowels (Fikkert and Levelt 2006).

Bernhardt and Stemberger (1998: 560-61) suggest that consonant-vowel place interactions may be the result of a constraint preferring uninterrupted gestures within a word, defined in (75).

(75) **Uninterrupted (F)**: A feature must be linked to all segments within the span of its spread (no segments may be skipped); e.g. **Uninterrupted (+voice)** (favors intervocalic voicing).

---

[78] A child with a phonological disorder is reported to have taken this pattern even further, with coronals occurring only before front vowels and velars only before back vowels, regardless of which was underlying (Dinnsen 2008a).

The constraint **Uninterrupted(Dorsal)** favors an uninterrupted dorsal gesture. In the case of velar harmony, since velar consonants are [+back], an uninterrupted gesture is only possible if the intervening vowel is also [+back]; otherwise the gesture will be interrupted by the intervening vowel. If faithfulness constraints do not permit changes to the vowel's features, highly ranked **Uninterrupted(Dorsal)** will only favor velar harmony with back vowels. This is illustrated in (76), where **Uninterrupted(Dorsal)** selects velar harmony in *coat* even when **Agree(Lingual)** has already been demoted to permit Dorsal…Coronal sequences.

(76) Persistent velar harmony with back vowels

Input: *coat* /koʊt/	[koʊt]	[toʊt]	[koʊk]
Uninterrupted(Dorsal)	*!		
Survived(Dorsal)		*!	
SinglyLinked(Dorsal)			*
Agree(Lingual)	*		

The emphasis of the present model is that the child's learning task involves the acquisition of consonant features not only individually, but also in sequence. Strikingly, Grace did not even attempt the word *pocket* until after she had mastered both Labial…Dorsal and Dorsal…Coronal sequences in monosyllabic words. At 1;8, after acquiring both of these sequences, she combines them in *pocket* [pakət] without error. With this view of consonant acquisition, it becomes clear why some words are likely to pose more problems than others, simply by virtue of the complexity of their feature sequences. For example, Grace had particular difficulty with the word *music*, producing the unusual but consistent form [dʒuwɪk] at age 2;2. This may seem puzzling until we consider that /mjuzɪk/ requires not only four different places of articulation in sequence (labial, palatal, coronal, dorsal), but four different manners of articulation (nasal, glide, fricative, stop). While I will not attempt a formal derivation due to the myriad of constraints involved, the recombination of features in the output has a certain logic; the initial affricate preserves the manner, place and voicing of the /z/ as well as the place features of the palatal glide in the onset cluster; the medial [w] preserves [+continuant] and [voice] along with the labiality of the /m/; and the final velar stop remains intact.

Having demonstrated how constraints governing the acquisition of consonant sequences help us derive the particular harmony and metathesis patterns found in Grace's data, I now proceed to a broader discussion of how the model can account for the harmony and metathesis trends attested across children. I also further examine how and why these processes are eliminated in the course of phonological development.

4 Explaining common harmony and metathesis patterns

"The short answer is: children learn to say sequences of segments, not just segments."

--Lise Menn (1983: 244)

4.1 Implicational tendencies for consonant harmony and metathesis

A satisfactory analysis of consonant harmony (CH) and long-distance metathesis should help us understand why these processes emerge in phonological development, how they are related, and the reasons behind common patterns observed across children. In addition, it should provide a framework for understanding how and why CH and long-distance metathesis of major place features are eliminated in the course of phonological development, such that they are unattested in adult phonology. In the previous chapter, I showed how the Bernhardt and Stemberger (1998) variant of OT helped make sense of the CH and metathesis patterns in Grace's longitudinal data. In this chapter, I further discuss how the acquisition of place sequences and the role of default and non-default features in speech planning are key to understanding patterns attested across children. With the addition of a Lingual node and a constraint on initial dorsals (proposed below), I argue that this model provides better empirical coverage of the range of CH and metathesis patterns attested and a more principled way of understanding these patterns.

As a point of departure, consider the implicational generalizations for CH observed by Pater (2002), repeated in (77).

(77) Consonant harmony implicational generalizations (Pater 2002)

a. Undergoer: Non-Coronal implies Coronal

b. Trigger: Labial implies Velar

c. Direction: Perseveratory implies Anticipatory

To review, the generalization regarding undergoers in (77)a states that if non-coronal consonants undergo harmony within a child's grammar as in *cup* [pʌp], coronal consonants undergo harmony as well, as in *boat* [boʊp]. Concerning triggers, if labials trigger assimilation as in *boat* [boʊp], velars do as well as in *coat* [koʊk]; in other words, the presence of labial harmony in a child's speech implies the presence of velar harmony. Finally, the presence of perseveratory harmony in a child's grammar implies the presence of anticipatory harmony, meaning that harmony is either bidirectional or exclusively anticipatory, but never exclusively perseveratory.

Pater (2002) proposes an account of these CH tendencies within Optimality Theory using a fixed markedness scale for place of articulation and targeted faithfulness constraints. The markedness scale in (78) places Dorsal as the most marked place of articulation, based on evidence from assimilation patterns in a variety of languages (de Lacy 2002). The scale-referring faithfulness constraints posited in (79) have the effect of deriving the preference to preserve the more marked Labial over Coronal place, and further to preserve the even more marked Dorsal over either Labial or Coronal place.

(78) Markedness scale for place of articulation assumed in Pater (2002)
Dorsal > Labial > Coronal

(79) Faithfulness constraints (Pater 2002)
(where P=Labial, T=Coronal, and K=Dorsal)
FAITH(K), FAITH(KP), FAITH(KPT):
Any correspondent of an input segment specified as X must be homorganic with the input segment (i.e. must have the same place of articulation)

In addition, Pater (2002) posits a specific set of agreement constraints governing the features that must agree as well as the directionality of agreement, as in (80).

(80) Agreement constraints driving CH (Pater 2002)
where P=Labial, T=Coronal, and K=Dorsal

←PK→	Any C preceding/following a dorsal or labial is homorganic
←PK	Any C preceding a dorsal or labial is homorganic
←K→	Any C preceding/following a dorsal is homorganic
←K	Any C preceding a dorsal is homorganic

The agreement constraints in (80) work in conjunction with the faithfulness constraints in (79) to derive the trigger and directionality implications, in that there are constraints promoting harmony of both labials and dorsals, and constraints promoting only dorsal harmony, but no constraint promoting only labial harmony. Similarly, there are constraints promoting bidirectional harmony and constraints promoting only anticipatory harmony, but none promoting only perseveratory harmony.

As demonstrated in Pater (2002), various re-rankings of these constraints successfully derive the CH tendencies outlined in (77). However, as acknowledged in Pater and Werle (2003), they do not allow for deviation from these tendencies such as labial harmony in the absence of velar harmony, a pattern that is occasionally attested (e.g. Fikkert, Levelt, and van de Weijer 2002). Furthermore, positing specific agreement constraints for directionality and faithfulness to the more marked feature does not address the principles underlying these tendencies. What is the grounding for the constraints driving CH in children? How do we account for the emergence and disappearance of CH in the course of phonological development? Finally, the use of agreement constraints to drive harmony does not shed light on the parallels between long-distance metathesis and CH patterns, which both affect major place features and are eliminated in the course of phonological development.

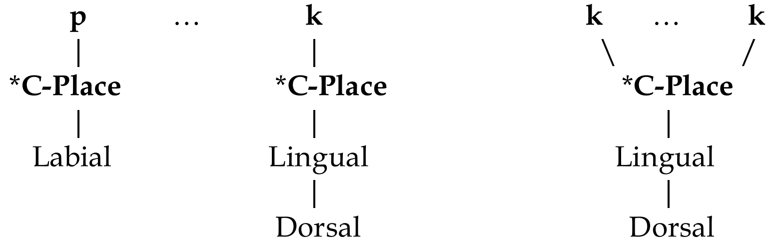
In order to understand the parallels between CH and metathesis observed in Chapter 3, we need to view both processes in the context of the acquisition of place feature sequences. This approach allows us to understand not only the implicational tendencies for CH in (77), but also typical patterns of long-distance place metathesis. In the following sections I examine the tendencies for harmony undergoers, triggers, and directionality in turn, as well as related tendencies for long-distance metathesis.

4.1.1 Undergoers

As discussed in 2.2.2, default feature values are derived from frequency in the input. Due to its high frequency, [Coronal] is typically the default place feature and is easiest to access in speech planning. With this in mind, the first implicational tendency in (77)a may be restated in terms of the present framework as the general prediction that "harmony between two non-default place features implies the presence of harmony between one non-default place feature and default place" (Bernhardt and Stemberger 1998: 559). In other words, harmony undergoers may initially include both default and non-default features but later may be limited to (default) coronal segments, but not vice versa. One factor contributing to this pattern is the common constraint limiting early words to a single consonant place feature, attributed in 3.2.2 to an undominated **Agree(C-Place)** constraint prohibiting sequences of C-Place feature nodes that dominate different dependent features. This constraint may be satisfied by harmony, creating shared place features, as illustrated in (81)b.

(81) Sample outputs for /p…k/ evaluated by **Agree(C-Place)**

a) Prohibited b) Permissible (shared place)



An undominated **Agree(C-Place)** constraint, characteristic of the initial stage, requires agreement of all place features, which includes a sequence of non-default features. Given a sequence of labial and dorsal segments, one non-default place feature should assimilate to the other in order to avoid an **Agree(C-Place)** violation.[79] This constraint therefore contributes to the early susceptibility of all place features to harmony.

After this limitation has been overcome, CH (and metathesis) patterns will be determined by the specific consonant place sequences that have been acquired by the child. In terms of the model, the demotion of **Agree(C-Place)** reveals the relative ranking of more specific feature sequence constraints, including **Agree** constraints for lower feature nodes such as Lingual or Dorsal, as well as **NoSequence** constraints

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[79] Alternatively, **Agree(C-Place)** could be satisfied by deleting one of the consonants entirely, as in *book* [ʊk]. Deletion as a response to sequence constraints is discussed in Chapter 5.

governing particular orderings of features (e.g. **NoSequence(Labial…Dorsal)**). The primary reason why coronal is most susceptible as an undergoer of harmony is its status as the default place feature and the underspecification of coronals, reflected in the lack of a **Survived(Coronal)** constraint mandating preservation of [Coronal] in the output. As discussed in 2.2.5, [Coronal] is inserted by default in the absence of any other place specification since the constraint against [Coronal] place is lowest ranked.[80] For reasons discussed in 2.2.5, I assume that an **Identical(Lingual)** constraint applies to the predictable feature [Lingual], ranked below the **Survived** constraints for non-default features. The complete hierarchy of constraints needed for faithful production of place features is repeated in (82).

(82) Ranking of faithfulness constraints and **Not** constraints for place features

Survived(Dorsal), Survived(Labial)
===========================
Not(Dorsal),[81] **Not(Labial), Identical(Lingual)**
===========================
Not(Coronal)

This ranking makes underspecified coronals particularly susceptible to assimilation, since **Survived(Labial)** and **Survived(Dorsal)** will always select preservation of the non-default feature. This is shown in the example in (83) of anticipatory labial harmony in *top* [pap], assuming a highly ranked **NoSequence(Lingual…Labial)** ruling out a faithful pronunciation.

---

[80] This assumes a **Survived(C-Place)** constraint, since otherwise the place node could be deleted entirely, resulting in a placeless glottal (as occurs in debuccalization). This constraint is not relevant for the discussion of harmony and metathesis, but will be used in the analysis of initial consonant deletion in Chapter 5.

[81] As discussed in Chapter 3, Bernhardt and Stemberger (1998) assume a typical ranking of **Not(Dorsal)** >> **Not(Labial)** but leave room for variation. I take a conservative position and do not assume a relative ranking between constraints against non-default features unless indicated by the data.

(83) Default place Coronal assimilates to non-default place

Input: *top* /tap/	[tap]	[tat]	[pap]
NoSequence(Lingual…Labial)	*!		
Survived(Labial)		*!	
Not(Labial)			*
SinglyLinked(Labial)		*	*
Identical(Lingual)			*
Not(Coronal)		*	

NoSequence(Lingual…Labial) need only be ranked as high as **Survived(Labial)** to motivate a coronal to undergo harmony, as long as both are ranked above **SinglyLinked(Labial)**. However, in order to motivate a non-default feature such as [Labial] to undergo harmony, **NoSequence(Lingual…Labial)** must be ranked in the highest stratum, as illustrated in (84) for *cup* as [kʌk]. Otherwise, the faithful output will be selected as optimal. To decide between labial and velar harmony in this hypothetical example, I assume the ranking **Survived(Dorsal)** >> **Survived(Labial)**, which is evident in some children.

(84) Non-default feature as undergoer of harmony[82]

Input: *cup*/kʌp/	[kʌp]	[pʌp]	[kʌk]
NoSequence(Lingual…Labial)	*!		
Survived(Dorsal)		*!	
Survived(Labial)			*
SinglyLinked(Place)		*	*

---

[82] I omit the **Not(Feature)** constraints from this and following constraint tables, as they do not affect selection of the optimal output.

If **NoSequence(Lingual…Labial)** is ranked high enough to motivate harmony over non-coronals (i.e. above the **Survived** constraints for non-default features), it will also motivate harmony over coronals. This is illustrated in the multiple-input constraint table in (85), where I consider how an undominated **NoSequence(Lingual…Labial)** constraint affects the output in target Dorsal…Labial and Coronal…Labial sequences, illustrated in production of *cup* v. *top*.

(85) Non-coronal as harmony undergoer implies coronal as undergoer

	Input: *cup*/kʌp/			**Input:** *top*/tap/	
	[kʌp]	[pʌp]	[kʌk]	[tap]	[pap]
NoSequence(Lingual…Labial)	*!			*!	
Survived(Dorsal)		*!		N/A	N/A
Survived(Labial)			*		*
SinglyLinked(Place)		*	*		
Identical(Lingual)			*		*

While non-coronals imply coronals as undergoers of harmony, the reverse seems to hold true for metathesis: coronal participation in metathesis implies participation of non-coronals. That is, metathesis of a Coronal…Labial sequence implies metathesis of Dorsal…Labial in children who have acquired velars[83] (Ingram 1974, Jaeger 1997), but not vice versa, reflected in the fact that metathesis is often reported only in Dorsal…Labial sequences. This is also predicted by the model. Since long-distance place metathesis incurs three violations of **Linearity** but harmony incurs only one violation of **SinglyLinked(C-Place) (**the constraint against spreading), a coronal can only be susceptible to metathesis if **Linearity** is ranked below **SinglyLinked(C-Place)**, as shown in (86). Otherwise, the multiple **Linearity** violations incurred by the metathesis candidate would result in harmony being selected as optimal.

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[83] An apparent exception is Si (Macken 1979), who avoided Dorsal…Labial sequences altogether until she acquired Lingual…Labial sequences at age 2;1.

(86) Ranking of **SinglyLinked(Place)** >> **Linearity** for Coronal metathesis

Input: *top* /tap/	[tap]	[tat]	[pat]	[pap]
NoSequence(Lingual…Labial)	*!			
Survived(Labial)		*!		
SinglyLinked(Place)				*!
Identical(Lingual)				*
Linearity			***	

Metathesis of coronals and labials is therefore evidence of a ranking of **SinglyLinked(Place) >> Linearity**. Given this ranking, problematic Dorsal…Labial sequences will also be repaired by metathesis rather than harmony. More generally, a child with metathesis of coronal and labial segments will not exhibit harmony, since changing the order of features is preferable to spreading a place feature. This generalization is true of the acquisition studies in which metathesis of coronals is reported (e.g. Ingram 1974, Berman 1977, Jaeger 1997).

The present model thus provides a new perspective on Macken's (1992) observation that early grammars can often be characterized by either "harmony templates" enforcing long-distance assimilation, or by "melody templates" involving rigid constraints on sequencing of place and manner features that produce metathesis, deletion or substitution. These different tendencies may be viewed in terms of the relative rankings of **SinglyLinked(Place)** and **Linearity**. While constraints on sequences of features are the driving force for both harmony and metathesis, the relative rankings of **SinglyLinked** and **Linearity** will determine whether harmony or metathesis dominates in a child's grammar.

In this section I have addressed the implication regarding undergoers of CH highlighted in Pater (2002), namely that non-coronals imply coronals as undergoers. In the earliest stage of acquisition, harmony is attributable to **Agree(C-Place)**, which prohibits any sequence of different place features and thus can enforce harmony with all places of articulation. Beyond the initial stage, harmony may be attributed to other sequence constraints, where coronals are particularly susceptible to assimilation due to the default status of [Coronal] and lack of an applicable **Survived** constraint.

I further proposed a novel but related implicational generalization for long-distance place feature metathesis, given in (87).

(87) Undergoers of metathesis: **Coronal** participants imply **non-coronals**

While non-coronal undergoers of harmony imply coronal, the reverse seems to be true for metathesis: coronal undergoers imply non-coronals (assuming velars are present in the child's system), because coronals can only be subject to metathesis if a ranking of **SinglyLinked(Place) >> Linearity** makes metathesis preferable to harmony. Thus in a given phonological system, we may find that coronals undergo harmony, while only non-coronals (i.e. labial and dorsal) undergo metathesis, as was the case in Grace's grammar. Both of these implicational generalizations for CH and metathesis fall out from the fact that **Survived** constraints for non-default features bias the system toward preservation of the non-coronal features [Labial] and [Dorsal].

Given that independent constraints govern the acquisition of specific sequences, it is theoretically possible that a highly ranked **NoSequence(Dorsal…Labial)** or **NoSequence(Labial…Dorsal)** could motivate only a non-default feature to undergo harmony after sequences involving coronals have already been acquired. However, there are a number of reasons this scenario is unlikely. One is that the desire to preserve both non-default places of articulation reflected in the **Survived** constraints for [Labial] and [Dorsal] can easily make metathesis rather than harmony the preferred repair for such sequences, as discussed above. In addition, sequences of non-coronals are unlikely to be the last sequences acquired, given that sequence constraints affecting coronals tend to remain highly ranked. For example, **Agree(Lingual)** can make coronals subject to velar harmony specifically in lingual sequences. There is also a strong tendency for Default…Non-default feature sequences such as Coronal…Labial and Coronal…Dorsal to be acquired late and remain susceptible to harmony (Macken 1992, Stemberger and Bernhardt 1997). The reasons for this tendency are discussed in the following section.

4.1.2 Directionality

Returning to Pater's generalizations, I turn my attention to the tendency regarding directionality in (88)c.

(88) Consonant harmony implicational generalizations (Pater 2002)

  a. Undergoer: Non-Coronal implies Coronal (addressed in Section 4.1.1)
  b. Trigger: Labial implies Velar
  c. **Direction**: **Perseveratory implies Anticipatory**

The generalization that the presence of perseveratory harmony implies anticipatory harmony may be restated as the generalization that perseveratory harmony implies *bidirectional* harmony. That is, across children, harmony is bidirectional in its earliest stages, and later limited to the anticipatory type. Stoel-Gammon (1996) observes this implication in her study of velar harmony in English (see also Donahue 1986: 216), while Pater (2002) makes the observation for all harmony types. The reasons for this implication become clear when we consider how the acquisition of consonant place feature sequences proceeds in the present model. Harmony is typically bidirectional in the initial stage of acquisition due to highly ranked **Agree(C-Place)**, which enforces only one place specification in a given word, but no preference in terms of directionality. Since **Agree** constraints prohibit any sequence of two consonants differing in the specified feature node, the order of the particular features is irrelevant. Default [Coronal] will always assimilate to a non-default place feature due to the latter's **Survived** constraint, so harmony over coronals motivated by **Agree** constraints is of necessity bidirectional.[84] As illustrated in (89), the direction of assimilation is determined by the position of the non-default feature in the sequence.

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[84] Although less common, harmony involving two non-default features may also be bidirectional if **Survived(Dorsal) >> Survived(Labial)**. For example, Trevor had consistent labial to velar assimilation at age 1;5, when both *bug* and *cup* were realized as [kʌk] (Compton and Streeter 1977, Pater and Werle 2003).

(89) Bidirectional harmony over coronals enforced by **Agree(C-Place)**

	Input: *top*/tap/				**Input:** *pot*/pat/		
	[tap]	[tat]	[pap]		[pat]	[tat]	[pap]
Agree(C-Place)	*!				*!		
Survived(Labial)		*!				*!	
SinglyLinked(Place)		*	*			*	*
Identical(Lingual)			*				*

Once **Agree(C-Place)** has been demoted, children begin acquiring their first sequences of place features. Most often the first sequence is a Labial…Coronal sequence (MacNeilage and Davis 2000), meaning that bidirectional labial harmony over coronals is eliminated. However, bidirectional velar harmony over coronals can persist due to highly ranked **Agree(Lingual)**, the **Agree** constraint for the next lower node in the place hierarchy. Once a child has demoted **Agree(Lingual)** (i.e. has acquired a sequence of lingual consonants), there are no other constraints that would enforce bidirectional harmony. Instead, **NoSequence** constraints prohibiting a specific ordering of features such as Coronal…Labial will typically motivate unidirectional harmony.

When harmony is no longer bidirectional, it is typically anticipatory, as reflected in the **Priority(Last, X)** constraint introduced in 2.2.5. For consonant place harmony, **Priority(Last, C-Place)** is the relevant constraint. In a disfavored sequence, all other things being equal, the anticipation of a following consonant's features will favor assimilation to its place of articulation. This was illustrated above in Grace's minimal pair *kitchen* [tɕɪtɕən] and *chicken* [kɪkɛn], where **Agree(Dorsal)** prohibited a sequence of consonants with differing [Dorsal] features. Since **Survived(Dorsal)** applied equally to both segments, it could not determine directionality, and anticipatory harmony was selected by **Priority(Last, C-Place)**.

The default or non-default status of features also interacts with speech planning principles to favor anticipatory harmony. The fact that non-default features are more difficult to access is reflected in the higher ranking of **Not(F)** constraints for these features compared to the defaults. In order for a non-default feature to be produced, a strong connection must be established to its specification in the lexicon, modeled by **Survived(F)** constraints for non-default features. The imbalance in the strength of the lexical connection can make sequences of a default followed by a non-default feature particularly challenging in acquisition (Stemberger and Bernhardt 1997), since the tendency to anticipate the lexical connection to the non-default feature complicates the speech planning task. In terms of the present framework, this is reflected in rankings of the type **NoSequence(Default…Non-default) >> NoSequence(Non-default…Default)**, leading to a tendency for harmony to persist in Default…Non-default sequences. By contrast, Non-default…Default sequences tend to be acquired first, and therefore harmony is eliminated first in these sequences. This corresponds with Macken's (1992) observation that coronal-initial words tend to undergo harmony, while coronal-final words do not.[85]

Thus in the present model, the implication that the presence of perseveratory harmony implies bidirectional harmony is explained by the role of **Agree** constraints in the acquisition of consonant sequences along with the anticipatory nature of speech planning reflected both in **Priority(Last,X)** and the higher ranking of **NoSequence(Default…Non-default)** type constraints. Initially, **Agree(C-Place)** can motivate bidirectional labial and velar harmony, and subsequently **Agree(Lingual)** may cause bidirectional velar harmony. Harmony motivated by **NoSequence** constraints frequently involves Default…Non-default sequences, where the tendency to anticipate a non-default feature causes persistent anticipatory harmony. Finally, in sequences of

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[85] While I focus here on place harmony, the anticipation of non-default features is also reflected in manner harmony patterns, e.g. anticipation of [+lateral] in *yellow* [lɛluː] (Smith 1973); anticipation of [+continuant] in Spanish *taza* 'cup' [sasa] (Macken 1978); and especially nasal harmony, which is common in [-nasal…+nasal] sequences but not the reverse (Stemberger and Bernhardt 1997), even across word boundaries as in *big moose* [mɪ mu] versus *mama's key* [mɔ ki] (Matthei 1989).

non-default features where **Survived** constraints are not decisive, anticipatory harmony is favored by **Priority(Last,X)**.

Ideally, the model would also account for the typical directionality of metathesis. Recall that metathesis often favors sequences with the more front articulation first (Ingram 1974). This direction of metathesis for target Coronal…Labial sequences as in *top* [pat] is in fact predicted by the ranking **NoSequence(Default…Non-default) >> NoSequence(Non-default…Default)** discussed above, which would prefer a Labial…Coronal sequence. While anticipatory harmony is common for Coronal…Labial sequences due to anticipation of the non-default feature, a ranking of **SinglyLinked >> Linearity** will result in metathesis instead, as shown above in (86).

An extension of this preference for Non-default…Default sequences could account for cases in which metathesis proceeds in the *opposite* direction of the fronting tendency. As discussed in 3.1.2, a metathesis pattern preferring initial dorsals is attested in a few studies (Grammont 1916, Smith 1973, Berman 1977), and Macken (1992) describes an English-acquiring child's consonant sequence template that permitted only velar consonants in initial position. This is not unexpected if the preference for a non-default feature to precede the default (most frequent) feature extends to a preference for the *least* frequent feature to appear first in the sequence. In English as well as many other languages, the least frequent place of articulation for consonants is dorsal (Locke 1983 and references cited therein). This may lead to a preference for dorsal-initial sequences in some children. This is consistent with the patterns reported for both Amahl (Smith 1973) and Shelli (Berman 1977), who preferred Labial…Coronal to Coronal…Labial sequences, conforming to the Non-default…Default preference.

Thus the Non-default…Default ordering preference influences not only the tendency for anticipatory harmony, but also the typical fronting metathesis pattern observed in Coronal…Labial sequences and a less typical metathesis pattern preferring initial dorsals. However, it does not explain the fronting metathesis pattern that often applies to the dorsal-initial sequences Dorsal…Labial and Dorsal…Coronal (Ingram 1974). This suggests that there is something about the initial dorsal that tends to trigger metathesis. This possibility is explored in the next section, where I address harmony and metathesis triggers.

4.1.3 Triggers and the role of initial dorsals

The final CH tendency to be addressed concerns harmony triggers, repeated in (88)b.

(90) Consonant harmony implicational generalizations (Pater 2002)
    a. Undergoer: Non-Coronal implies Coronal (addressed in 4.1.1)
    b. **Trigger**: **Labial implies Velar**
    c. Direction: Perseveratory implies Anticipatory (addressed in 4.1.2)

According to Pater (2002), if labials trigger harmony in a given child's grammar, velars do as well; that is, the presence of labial harmony in a grammar implies the presence of velar harmony, but not vice versa. This claim in its strictest form is too strong, since labial harmony can and frequently does occur without velar harmony in children who have not yet acquired velars (e.g. Donahue 1986, Berg 1992, Stoel-Gammon 1996). In the absence of velars, clearly velar harmony cannot occur. However, we may properly evaluate this implication for harmony triggers in children who have acquired velars. In the case of Sean (Donahue 1986), who initially had only labial harmony, velar harmony did appear after the acquisition of velars (e.g. *big goat* [gɪgok]), conforming to the implicational generalization.

It is true that labial harmony implies velar harmony in a number of studies of early acquisition (e.g. Ferguson et al. 1973, Smith 1973, Macken 1978, Donahue 1986, Pater 1997, Vihman and Velleman 1989, Rose and dos Santos 2006, Cruttenden 1978[86]). However, this tendency does not hold true consistently in cross-linguistic studies. Menn (1971: 237) reports that her subject Daniel eliminated velar harmony in *gate* before eliminating labial harmony in *boat*. Labial harmony in the absence of velar harmony is also reported in Dutch (Fikkert and Levelt 2008) and Italian (Keren-Portnoy et al. 2009).

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[86] Both labial and velar harmony are reported during the period of the study (age 1;6-2;2); however, the child is not followed to the point of elimination of either labial or velar harmony.

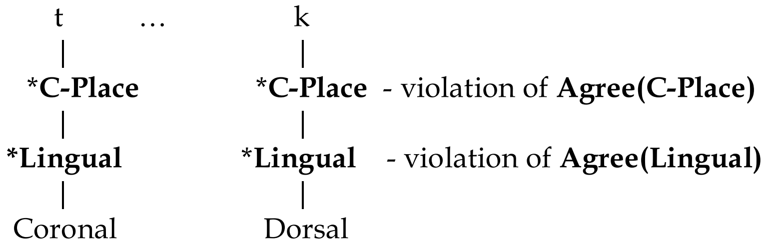
The set of universal assimilation constraints in (80) posited by Pater (2002) do not allow for the variation in harmony patterns attested in children since there is no agreement constraint that targets only labials in the absence of velars.

In regards to metathesis triggers, initial dorsals tend to trigger fronting metathesis, as seen in *cup* [pʌk] and *kite* [taɪk], suggesting that dorsal-final sequences are easier to acquire (Ingram 1974). However, the suggestion that Coronal…Dorsal sequences should be acquired earlier than Dorsal…Coronal sequences is at odds with the frequency and persistence of anticipatory velar harmony in Coronal…Dorsal sequences (Stoel-Gammon 1996), implying late acquisition of this sequence. In fact, we find both orders of acquisition attested in the literature; Dorsal…Coronal sequences are acquired first in children with persistent anticipatory velar harmony (Stoel-Gammon 1996, Menn 1975, Smith 1973, Pater 2002; Keren-Portnoy et al. 2009), while Coronal…Dorsal sequences are acquired first in children with fronting metathesis (Ingram 1974, Jaeger 1997).

Thus we observe two inconsistencies in claims regarding the order of acquisition of place sequences. Pater (2002) claims that labial harmony implies velar harmony, suggesting that lingual sequences are the last sequences acquired, but children vary in this respect. Fronting metathesis triggered by initial dorsals implies that Coronal…Dorsal sequences should be acquired before Dorsal…Coronal, but many children with anticipatory velar harmony have the reverse acquisition pattern. This variation is a problem for the fixed constraint set in Pater (2002) as well as for the fronting constraint suggested in Ingram (1974). The present model, as I will show in this section, is flexible enough to allow for this variation while still making valid predictions about likely acquisition patterns.

In the current model, the order of acquisition of place sequences is limited only by the fact that the demotion of **Agree** constraints must progress from the C-Place node at the top of the hierarchy to successively lower nodes (first Lingual, then Dorsal or Coronal). This is necessary since a violation of **Agree** for a lower node entails a violation of **Agree** for a higher node. For example, a violation of **Agree(Lingual)** entails a violation of **Agree(C-Place)**, as illustrated in the Coronal…Dorsal sequence in (91).

(91) **Agree** constraint violations for a sequence of lingual articulations



The generalization that labial harmony often implies velar harmony follows from a common acquisition pattern: initially, highly ranked **Agree(C-Place)** causes both labial and velar harmony in children who have already acquired velars.[87] **Agree(C-Place)** is the first constraint to be demoted, unmasking the relative ranking of **NoSequence** constraints as well as the effects of **Agree** constraints for lower nodes in the hierarchy. If **Agree(Lingual)** remains highly ranked, the child's first sequences of different place features will involve a labial and a lingual. Rose and dos Santos (2006) suggest that for articulatory reasons, sequences of labials and linguals should be easier to acquire than sequences of different lingual articulations, although they do not posit a constraint to account for this generalization. In the present model, **Agree(Lingual)** reflects the additional challenge of coordinating two different gestures with the same articulator (i.e. the tongue). If **Agree(Lingual)** causes lingual sequences to be acquired later, then it follows that velar harmony will persist longer in the child's grammar, leading to the tendency for labial harmony to imply velar harmony.

However, this is only one possible order of acquisition. Since the ranking of **Agree(Lingual)** is independent from the ranking of **NoSequence** constraints involving a labial, there are a number of possible acquisition patterns. A constraint such as **NoSequence(Coronal…Labial)** need not be demoted prior to **Agree(Lingual)**, but may

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[87] Undominated **Agree(C-Place)** is characteristic of many children's grammars at the onset of speech, but this constraint may be demoted during the babbling stage. If this is the case, the child's first words can include sequences of different place features.

remain highly ranked even as lingual sequences are acquired. This is the order of acquisition attested in five Dutch-acquiring subjects (Fikkert and Levelt 2008). Like most children, they acquire Labial…Coronal sequences first. Next, however, they acquire the dorsal-final sequences Labial…Dorsal and Coronal…Dorsal. The last sequences acquired are dorsal-initial sequences and Coronal…Labial sequences. Since Coronal…Labial is among the last sequences acquired, this results in labial harmony in the absence of velar harmony, a pattern that is easily accommodated in the present framework by the late demotion of **NoSequence(Coronal…Labial)**, which follows the tendency for Default…Non-default feature sequences to be later acquired.

Fikkert and Levelt (2008) posit two emergent constraints to account for the patterns observed in the acquisition of place sequences in their five Dutch-acquiring subjects: an alignment constraint preferring initial labials abbreviated as **[Labial**[88] and a constraint against initial dorsals abbreviated as ***[Dorsal**. In the present model, a special alignment constraint for [Labial] is not needed to account for the Dutch harmony patterns, since the Default…Non-default nature of a Coronal…Labial sequence provides a principled explanation for why this sequence is often acquired late. However, there is reason to believe that a constraint like ***[Dorsal** plays a role in many developing grammars, not just in children acquiring Dutch. While the Non-default…Default preference leads us to expect a ranking of **NoSequence(Coronal…Dorsal) >> NoSequence(Dorsal…Coronal)**, a constraint against initial dorsals could make dorsal-initial consonant sequences problematic for some children, resulting in the later acquisition of these sequences and the tendency for initial dorsals to trigger metathesis.

It is important to establish the grounding of any proposed production constraint. While a constraint against initial dorsals has been proposed in some form by a number of researchers (Fikkert, Levelt, and Van de Weijer 2002; Fikkert and Levelt 2008; Morrisette et al. 2003; Inkelas and Rose 2008), justification for the constraint has varied. Fikkert and

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[88] Fikkert and Levelt (2008) suggest that **[Labial** is related to the high frequency of labial-initial words in Dutch child-directed speech; however, this is inconsistent with statistics cited in Fikkert, *et al.* (2002) indicating that 25% of word-initial consonants are labial, while 51% are coronal.

Levelt (2008) claim that a constraint against initial dorsals emerges from the low frequency of velar stops in initial position in Dutch. However, their suggestion that this emergent constraint leaves a trace in the adult grammar in the relatively low frequency of dorsal-initial words in Dutch (Fikkert and Levelt 2008: 254), results in the circular claim that low frequency in initial position is both a source and an eventual consequence of the constraint.

The low frequency of initial dorsals in Dutch (and other languages) might instead reflect an articulatory reason to disprefer velars in this position. In fact, dorsal is the least frequent place of articulation word-initially (after coronal and labial) in a variety of modern languages surveyed, including English, Dutch, German, French, Italian, Spanish, Czech, Polish, Hungarian, Finnish, and Yoruba (Janda 1979, cited in Locke 1983).[89] Locke observes that the frequency of velars in English and Czech acquisition is skewed by word position, noting that in "in word-initial position a velar seems quite out of its element, practically a 'sitting duck' for the alveolar intruder, though it is quite secure in final position" (1983: 176-177). Furthermore, the fact that velar nasals are specifically lacking word-initially in a wide variety of European, Asian, Siberian, and Native American languages[90] (Anderson 2008) suggests that there may be a physiological basis for a constraint against an initial dorsal feature, perhaps especially in co-occurrence with other non-default features such as [nasal].

Velar fronting patterns in phonological development provide additional evidence for a constraint against initial dorsals. Velar fronting is a fairly common pattern in early speech whereby velars are substituted by alveolars, as in *key* [tiː] and *go* [doʊ]. In a study of 51 normally developing children from age nine months to two years, nearly half of the subjects (24 of 51) produced forms with velar fronting (Stoel-Gammon and Stemberger 1994).[91] This context-free substitution pattern is easily characterized by a

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[89] An exception was Swahili, where labials are least frequent word-initially.

[90] Of 234 languages with a phonemic velar nasal, 88 (over 37%) lack it word-initially.

[91] Although I focus on English acquisition, velar fronting is also reported in other languages, such as Dutch (Fikkert 1994), German (Berg 1995), and Japanese (Ueda 1996), and is said to be common in Chinese (Chao 1971: 118).

ranking of **Not(Dorsal) >> Survived(Dorsal)**, with coronals being selected as the optimal substitute due to the low ranking of **Not(Coronal)** as well as the faithfulness constraint **Identical(Lingual)**. Once acquisition of velars begins, however, a somewhat unexpected pattern emerges. Velars are often acquired first word-finally in English, while still being fronted word-initially, as illustrated in (92). The same pattern is reported for a German-acquiring child (Melanie, Berg 1995) as well as in data from Dutch-acquiring children (e.g. Jarmo, Fikkert 1994).

(92) Typical velar acquisition patterns

a) Velars word-finally (Stoel-Gammon 1996)
bug [bʌg]   *take* [teɪk]   *cook* [tʊk]

b) Fronting word-initially
cup [tʌp]   *game* [deim]   *kick* [tɪk]   (Stoel-Gammon 1996)
kiss [tɪs]   *good-bye* [ˌdʊˈbɑɪ]   *karate* [təwɑdi]   (Bills and Golston 2002)

This neutralization of place contrast in initial position is contrary to the predictions of positional faithfulness (Beckman 1997), which accords a higher ranking to faithfulness constraints in prosodically strong positions. We would normally predict more faithfulness to features such as [Dorsal] word-initially, especially in the onset of an initial stressed syllable, while neutralization would be more likely in coda position. Yet in data from 67 children, Stoel-Gammon (1996) finds no examples of velar fronting only word-finally.

The context for early acquisition of velars is actually not limited to word-final position, but extends to most word-medial target velars as in *bucket* [bʌkət]. This pattern is documented in typically developing English-acquiring children (Leopold 1947, Stoel-Gammon 1996, Stemberger 1996a: 73, Bills and Golston 2002, Inkelas and Rose 2008) as well as in children with phonological delays (Chiat 1983, Morrisette et al. 2003).[92]

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[92] Dinnsen (2008b) highlights an implicational relationship between the acquisition of initial velars and that of post-vocalic velars. In children with phonological delays whose treatment for velar fronting focused on coda position, velar production was not generalized to initial position. Children whose treatment focused on initial velars, however, acquired velars in all contexts.

Interestingly, where complete data on positional velar fronting is available (e.g. Chiat 1983; Stoel-Gammon 1996; Bills and Golston 2002; and Inkelas and Rose 2008), medial velars are produced before an unstressed vowel but fronted before a stressed vowel, as illustrated in the minimal pair *Mikey* [ˈmaɪgi] and *my key* [maɪ.ˈtiː] (Chiat 1983). Additional examples of this positional velar fronting pattern are provided in (93) (Bills and Golston 2002, Inkelas and Rose 2008).[93]

(93) Typical word-medial velar acquisition patterns

a) Velars before an unstressed vowel

tiger [taɪgʌ] *tickle* [tɪko] *cooking* [tʊkɪŋ]

b) Fronting before a stressed vowel (primary or secondary stress)

again [əˈdɛn] *okay* [ˌoˈte] *pancakes* [ˈpænˌteks]

forgot [fɔˈdɑt] *because* [pəˈtʌz] *playground* [ˈpeˌdaʊn]

As observed in Bills and Golston (2002), the context for positional velar fronting may be characterized as foot-initial, meaning that the distribution of dorsals mirrors that of the velar nasal [ŋ] in English; e.g. *sing* [sɪŋ], *hangar* [hæŋəɹ] but *[ŋæp], *[ˌoˈŋe]. This begs the question of what is unique about foot-initial position that inhibits velar consonant production; or alternatively, what facilitates it in non-foot-initial position.

Inkelas and Rose (2007) suggest that this child-specific pattern emerges due to the child's larger tongue size relative to the oral cavity in combination with the enhanced, larger amplitude tongue gesture required in strong prosodic positions, yielding a greater area of linguo-palatal contact that results in the coronal release characteristic of fronted velars. However, reliance on this anatomical explanation seems to suggest that all children would experience the same difficulty, and that the lingual stop resulting from the attempt at a velar would fall somewhere on a continuum between velar and coronal, rather than the categorically coronal articulation frequently reported in the literature.

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[93] I also observed this tendency in "Emma," a child I interacted with as a caregiver. At 3;5 she did not produce velars consistently in all contexts. Velars were occasionally produced in stressed syllables in *key*, *go*, *cold*, and *cause*, but frequently fronted in *can*, *can't*, *kitty*, *kid*, *could*, *get*, *guess*, *got*, *good*, *guys*, and *again*. Medial and final unstressed velars were never fronted, however, appearing accurately in *talking*, *dogs*, *blanket*, *book*, *fix*, *broke*, *magic*, and *taking*.

Morrisette et al. (2003) also point out that positional velar fronting can persist in children with phonological delays as late as age eight, well past the point at which the child's vocal tract anatomy is proportionately adult-like.

Bernhardt and Stemberger (1998) take a different approach, suggesting that the pattern favoring velars in weak prosodic positions reflects the preference for elements in the syllable rime to have vowel-like features, assuming that all vowels have a [Dorsal] feature node (Clements and Hume 1995). They propose that the closed-open jaw cycle inherent in babbling leads to emergence of a **Co-occurring(Rime→Dorsal)** constraint that can favor velar production in the syllable rime, i.e. in coda position.[94] In order for this constraint to favor all non-initial velars, however, word-medial velars must be syllabified as the coda of the initial syllable (as in *bucket* [bʌk.ət]) rather than the onset of the following syllable (as in *bucket* [bʌ.kət] (Stemberger 1996a: 74), a claim that is somewhat controversial due to the oft-cited universal preference for open CV syllables.

In this view, the ranking **Co-occurring(Rime→Dorsal) >> Not(C-Dorsal) >> Survived(C-Dorsal)** would account for the typical positional velar fronting pattern (Stemberger 1996a, Bernhardt and Stemberger 1998), where **Not(C-Dorsal)** prevents velar production generally, but **Co-occurring(Rime→Dorsal)** favors velars in non-initial position. Under the assumption that coronals are underspecified, however, this incorrectly predicts that all coronal codas should become velars (Bernhardt and Stemberger 1998: 430-431). If **Co-occurring(Rime→Dorsal)** is ranked high enough to assist in the realization of a velar in the rime, it should force all coronal codas to surface as dorsal. This is shown in the multiple input table in (94), which correctly selects positional velar fronting in *cook* [tʊk], but incorrectly selects coronal backing in *dot* [dak], a pattern that is not attested.

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[94] In claiming that the optimal rime is [Dorsal], Bernhardt and Stemberger do not state that the optimal onset is a nondorsal, but leave the possibility open (1998: 213).

(94) Effect of **Co-occurring(Rime→Dorsal)** on velar codas

	/kʊk/			/dat/	
	[kʊk]	[tʊt]	[tʊk]	[dat]	[dak]?
Co-occurring(Rime→Dorsal)		*		*	
Not(Dorsal)	**![95]		*		*
Survived(Dorsal)		**!	*	N/A	N/A
Not(Coronal)		**	*	**!	*

In order to assist in the realization of a velar coda, **Co-occurring(Rime→Dorsal)** must be ranked at least as high as as **Not(Dorsal)**; otherwise, undominated **Not(Dorsal)** would prevent any velars from surfacing. As shown above, multiple violations of **Not(Dorsal)** rule out a fully faithful output, while violations of equally ranked **Not(Dorsal)** and **Co-occurring(Rime→Dorsal)** pass the decision between [tʊt] and [tʊk] to a lower ranked constraint.[96] The multiple violations of **Survived(Dorsal)** in [tʊt] select preservation of the velar coda as the optimal candidate. However, applying this same constraint ranking to an input with no underlying velars, as in *dot*, incorrectly selects a velar coda as optimal. As discussed in Bernhardt and Stemberger (1998: 431), avoiding this problem would require the use of an additional constraint such as **Lexical(Dorsal)** specifying that [Dorsal] may not be inserted (cf. DEP(FEATURE)) if not underlying. Since the **Not** constraint otherwise serves all of the purposes of the constraint against epenthesis DEP (McCarthy and Prince 1995), the addition of a **Lexical** constraint would complicate the model. It seems undesirable to invoke this constraint if it is not independently required in other contexts.

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[95] Repetition of the [Dorsal] feature incurs either two violations of **Not(Dorsal)** or, if [Dorsal] place is shared, one violation of **Not(Dorsal)** and one violation of **SinglyLinked(Dorsal)**. In this example, the same result obtains if these constraints are ranked in the same stratum.

[96] I do not consider the unattested output [kʊt] in the table (with fronting of the coda velar only) because it would have no advantage over the other candidates, seeing as it violates both **Not(Dorsal)** and **Co-occurring(Rime→Dorsal)**.

Formulating the constraint in the negative, following Fikkert and Levelt (2008) and Morrisette et al. (2003), avoids this problem. Since fronting also occurs in word-medial stressed syllables as in (93) above, the constraint must apply specifically to foot-initial onsets in order to account for all of the positional velar fronting data. In the Bernhardt and Stemberger (1998) framework, this constraint may be formulated as a negative constraint against the co-occurrence of the feature [Dorsal] and the foot onset, as defined in (95).

(95) **NotCo-occurring(Onset,Dorsal)**: The feature [Dorsal] may not co-occur with a foot-initial onset.

This context-specific negative output constraint correctly selects velar codas in target velars while not overgenerating velar codas for underlying coronals, as shown in (96).

(96) Correct predictions of **NotCo-occurring(Onset,Dorsal)** for velar codas

	/kʊk/			/dat/	
	[kʊk]	[tʊt]	[tʊk]	[dat]	[dak]
NotCo-occurring(Onset,Dorsal)	*				
Survived(Dorsal)		**!	*	N/A	N/A
Not(Dorsal)	**!		*		*!
Not(Coronal)		**	*	**	*

This pattern results when faithfulness is ranked above the general output constraint, in this case **Not(Dorsal)**, but not above the context-specific constraint **NotCo-occurring(Onset,Dorsal)**. As shown in (97), the ranking permutations of these output constraints with **Survived(Dorsal)** all result in attested grammars, while not predicting an unattested grammar in which velars are absent only in codas.

(97) Ranking permutations and predictions for velar acquisition

a) No velars (both output constraints ranked above faithfulness):
NotCo-occurring(Onset,Dorsal), **Not(Dorsal)**[97] **>> Survived(Dorsal)**

b) No foot-initial velars (context-free constraint ranked below faithfulness):
NotCo-occurring(Onset,Dorsal), **Survived(Dorsal) >> Not(Dorsal)** *or*
NotCo-occurring(Onset,Dorsal) >> Survived(Dorsal) >> Not(Dorsal)

c) Velars in all positions (adult grammar; faithfulness ranked highest):
Survived(Dorsal) >> NotCo-occurring(Onset,Dorsal), Not(Dorsal) *or*
Survived(Dorsal) >> NotCo-occurring(Onset,Dorsal) >> Not(Dorsal)

This formulation of the constraint is formally adequate but still begs an adequate explanation. Bills and Golston (2002) suggest an interesting prosodic explanation for why dorsal consonants might first be acquired foot-internally. Like Bernhardt and Stemberger (1998), their account hinges on the inherent dorsality of vowels. They suggest that the dorsal closure of a velar stop is supported by the adjacent dorsal vowel feature in the same prosodic constituent, namely the foot rhyme, defined here as everything following the foot onset.[98] This approach suggests that features are more readily shared within a prosodic constituent than between prosodic constituents, assuming that the foot onset constitutes a separate prosodic constituent. The diagram in (98) illustrates how this [Dorsal] feature sharing supports (or licenses, in their terms) the velar stop in this position.

(98) Licensing of [Dorsal] in the foot rhyme (Bills and Golston 2002)

a) *take* b) *cookie*

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[97] The relative ranking of **NotCo-occurring(Onset,Dorsal)** and **Not(Dorsal)** is irrelevant, since as long as they are both ranked above **Survived(Dorsal)**, no velars will surface.

[98] Bills and Golston (2002) note that this definition of rhyme follows the usage of rhyme in English poetry since the 14th century.

This analysis makes sense from a speech planning perspective: velar consonants can be acquired more easily not only in codas, but also word-medially before an unstressed vowel, because in either case the dorsal features of the preceding vowel are in the same speech planning unit (the foot rhyme). Before a stressed vowel, however, velar fronting occurs (as in *okay* [ˌoˈte]), since this target velar begins a new foot (or speech planning unit). In addition, borrowing from the reasoning of Inkelas and Rose (2008) that an enhanced gesture is required for a velar closure in a stressed syllable, it may be that [Dorsal] closure requires more effort in this environment due to the lesser degree of fine motor control possible with the tongue body as opposed to the tongue tip or blade. Dorsal closure in a weak prosodic position, i.e. foot-internally, permits the preceding vowel to support such a gesture. These factors conspire to make velars harder to acquire in foot-initial position.

With this grounding in mind, positing the negative co-occurence constraint **NotCo-occurring(Onset,Dorsal)** would explain the conflicting orders of acquisition attested in sequences of lingual consonants, and specifically why one order of acquisition leads to persistent velar harmony as in *duck* [gʌk] while the other leads to metathesis as in *kite* [taɪk]. When Dorsal…Coronal sequences are acquired first, target Coronal…Dorsal sequences undergo velar harmony, but when Coronal…Dorsal sequences are acquired first, target Dorsal…Coronal sequences undergo fronting metathesis. The first scenario is shown in (99), where **NoSequence(Coronal…Dorsal) >> NoSequence(Dorsal…Coronal)** according to the Non-default…Default preference, and **Survived(Dorsal) >> Not(Dorsal)**, **NotCo-occurring(Onset,Dorsal)**, consistent with faithful production of velars in all contexts. In this scenario, harmony is selected as the preferred repair due to the **Linearity** violations incurred by metathesis.

(99) Harmony in a Coronal…Dorsal sequence

Input: *duck* /dʌk/	[dʌk]	[dʌt]	[gʌk]	[gʌt]
NoSequence(Coronal…Dorsal)	*!			
Survived(Dorsal)		*!		
Not(Dorsal)	*		*	*
SinglyLinked(Dorsal)			*	
NotCo-occurring(Onset,Dorsal)			*	*
NoSequence(Dorsal…Coronal)				*
Linearity(Place)				*!**

On the other hand, Coronal…Dorsal sequences are acquired first by some children, resulting in fronting metathesis of Dorsal…Coronal sequences. This can occur in spite of the ranking **NoSequence(Coronal…Dorsal) >> NoSequence(Dorsal…Coronal)** if the constraint against initial dorsals is ranked above both sequence constraints, as in (100).

(100) Fronting metathesis of a Dorsal…Coronal sequence

Input: *kite* [taɪk]	[kaɪt]	[taɪt]	[kaɪk]	[taɪk]
Survived(Dorsal)		*!		
Not(Dorsal)	*		*	
NotCo-occurring(Onset,Dorsal)	*!		*!	*
NoSequence(Coronal…Dorsal)				*
SinglyLinked(Dorsal)			*	
Linearity(Place)				***
Not(Coronal)	*	**		*
NoSequence(Dorsal…Coronal)	*			

In this scenario, **NotCo-occurring(Onset,Dorsal)** can tip the scales in favor of earlier acquisition of Coronal…Dorsal sequences.[99] Crucially, this order of acquisition does *not* lead to a pattern of perseveratory velar harmony, i.e. *kite* *[kaɪk], because of the highly ranked constraint against initial dorsals. Attributing the variation in order of acquisition of the lingual sequences Dorsal…Coronal and Coronal…Dorsal to the relative ranking of a constraint against initial dorsals explains why velar-coronal metathesis is typically triggered only by target Dorsal…Coronal sequences. It further explains why there is no comparable variation in order of acquisition of Labial…Coronal and Coronal…Labial sequences leading to metathesis of target Labial…Coronal sequences, since the constraint against initial dorsals is irrelevant for these sequences.

Because constraints are violable and vary in ranking, **NotCo-occurring(Onset,Dorsal)** will not cause observable effects in all children. Some children have already mastered velars in all contexts by the onset of meaningful speech. In such children, the preference for the least frequent place feature to appear first in the sequence may even lead them to acquire dorsal-initial sequences before the reverse, as discussed in 4.1.2 for the less typical direction of metathesis attested in Amahl (Smith 1973) and Shelli (Berman 1977), as well as the order of acquisition for Daniel (Menn 1975) and Trevor (Pater and Werle 2003), both of whom acquired Dorsal…Labial sequences while anticipatory velar harmony persisted in Labial…Dorsal sequences.

With this understanding of the factors involved in triggering harmony and metathesis, I address the CH trigger asymmetry claimed in Macken (1996), repeated in (101):

(101) Hierarchies for harmony triggers in CVC words (Macken 1996)

a. Onsets: Labial >> Dorsal >> Coronal

b. Codas: Dorsal >> Labial >> Coronal

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[99] With the ranking given in (100), an additional constraint would be needed to rule out metathesis of velar-initial CV sequences as in *key* [ik]. This type of metathesis could be ruled out either by **Co-occurring(σ→Onset)**, if highly ranked, or by a **Linearity(Root)** constraint disfavoring metathesis of entire segments (as opposed to place features).

This claim is somewhat difficult to evaluate in the absence of examples in Macken (1996), but it is true that dorsal codas trigger harmony more frequently than labials and often persist longest as harmony triggers, causing velar harmony in Coronal…Dorsal and sometimes Labial…Dorsal sequences. This follows from the anticipatory nature of speech planning and **Survived(Dorsal**). However, I have found no evidence for labial onsets as strong harmony triggers. Given the early acquisition of Labial…Coronal sequences in most children, labial harmony for this sequence (e.g. *boat* as [bop]) is typically limited to the initial "one place" stage of acquisition. Labial harmony for target Labial…Dorsal sequences (e.g. *pick* [pɪp]) is extremely rare in children with velars, whereas velar harmony for this sequence is not uncommon. This follows from the tendency for anticipatory assimilation reflected in the **Priority(Last,C-Place)** constraint.

I have shown in this section that the triggers of harmony and metathesis can be explained in the present model by the preference for Non-default…Default type sequences and the potential difficulty posed by foot-initial dorsals. Rankings of the type **NoSequence(Default…Non-default) >> NoSequence(Non-default…Default)** are to be expected from speech planning considerations, accounting for the prevalence of harmony in coronal-initial sequences, occasional metathesis of target Coronal…Labial sequences, and even a preference for dorsal-initial sequences in some children because [Dorsal] is the least frequent (or most marked) feature. A constraint against foot-initial dorsals, **NotCo-occurring(Onset,Dorsal)**, justified above for articulatory reasons,[100] can disprefer dorsal-initial sequences, leading to the fronting metathesis pattern observed in many children. A final variable for harmony trigger implications is the relative ranking of **Agree(Lingual)**. This constraint can cause velar harmony to persist longer in lingual sequences, supporting the claim that labial harmony implies velar harmony. However, it may also be demoted earlier in acquisition while Lingual…Labial sequences remain problematic, as attested in Dutch (Fikkert and Levelt 2008). With these factors in mind, I now proceed to a summary of harmony and metathesis patterns as they relate to the acquisition of consonant sequences.

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[100] Relevant acquisition data from a greater variety of languages would be useful in determining whether we are justified in positing this as a universal articulatory constraint.

4.2 Harmony and metathesis in phonological development

4.2.1 The acquisition of consonant sequences

While all place feature sequences may initially be subject to CH due to a limit of one consonantal place feature per word, certain sequences seem to be subsequently more or less susceptible to CH or metathesis. These patterns are inextricably linked to the order of acquisition of place feature sequences. I suggest that the relative difficulty of particular feature sequences can be traced to the interaction of three primary factors: the presence and position of the default feature [Coronal], potential articulatory difficulty with an initial [Dorsal] feature, and potential difficulty executing a sequence of similar but different lingual places of articulation. These factors are modeled as follows:

(102) Primary factors in the acquisition of consonant feature sequences

a. **NoSequence(Default…Non-default) >>**
   NoSequence(Non-default…Default)

b. **NotCo-occurring(Onset,Dorsal)**

c. **Agree(Lingual)**

These factors interact to produce the variety of CH and long-distance metathesis patterns attested in English.[101] To illustrate the influence of these factors, I have summarized common repairs for various sequences in Table 1, along with notable characteristics of each sequence. Where more than one repair is attested in multiple studies, the less common repair is listed in parentheses. I then discuss the relevant factors leading to common CH and metathesis patterns for each sequence in turn.

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[101] Although some of these generalizations may extend to languages other than English, I limit my claims to English acquisition due to insufficient data from other languages.

Table 1: Summary of common outputs for target place sequences in English

Target sequence	**Common repairs**	**Special characteristics**
Labial…Coronal e.g. /pat/	None	First sequence acquired for most children
Labial…Dorsal e.g. /pɪk/	None (or anticipatory velar harmony: [kɪk])	Both non-default features
Coronal…Labial e.g. /tap/	**Anticipatory labial harmony**: [pap] (or metathesis: [pat])	**Default…Non-default** sequence
Coronal…Dorsal e.g. /dʌk/	**Anticipatory velar harmony**: [gʌk]	**Default…Non-default** sequence, both lingual places of articulation
Dorsal…Coronal e.g. /kʌt/	Metathesis: [tʌk] (or velar harmony: [kʌk])	Initial dorsal; both lingual places of articulation
Dorsal…Labial e.g. /kʌp/	Metathesis: [pʌk] (or avoided)	Initial dorsal; both non-default features

Perseveratory labial harmony is the least common CH pattern attested in studies of phonological development. Even for target Labial…Coronal sequences, where we might expect assimilation of default coronal place to non-default labial, harmony is exceedingly rare, typically occurring only when a child's output is limited to one place feature per word (i.e. when **Agree(C-Place)** is undominated). As for metathesis, it is not attested for target Labial…Coronal sequences in my review of the literature. Instead, children usually produce this sequence faithfully, reflecting the fact that it is typically acquired first. In a review of seven reports of early phonological development in five different language communities (MacNeilage and Davis 2000), Labial…Coronal sequences were among the first sequences acquired in 21 of 22 infants. This was also the first sequence for another English-acquiring child not cited in their survey (Joan[102], Velten 1943), bringing the ratio up to 22 of 23 infants. This early preference for Labial…Coronal is also reported for the two children whose first sequences are documented by Velleman (1998: 65, 148-49). Grace's first differentiated sequence was also Labial…Coronal ([pas] for *splash*), although she acquired all Labial…Lingual sequences more or less simultaneously.

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[102] Joan was also exposed to and had passive knowledge of Norwegian and French.

MacNeilage and Davis (2000) suggest that the early acquisition of labial-initial sequences may reflect a preference to begin a word in an easy way, since a labial consonant closure requires only jaw oscillation with no tongue movement. They propose that an easy articulation is preferred in initial position due to the high functional load associated with initiating an utterance. However, as noted in MacNeilage et al. (1999), the high proportion of coronals in late babbling (see Locke 1983: 36-37) does not support the labial ease hypothesis. Coronals are usually considered to be the default place of articulation (Paradis and Prunet 1991) and therefore a greater ease in production could be argued for coronals over labials. Furthermore, the Non-default…Default preference discussed above (Bernhardt and Stemberger 1998) seems to indicate that the less accessible (or more difficult) place feature should come first, rather than the "easier" place of articulation.

MacNeilage and Davis (2000) further surmise that an early preference for initial labials may correlate with a high frequency of initial labials in a variety of languages (English, Estonian, French, German, Hebrew, Maori, Quichua, and Spanish, but not Japanese or Swahili). However, this conflicts with data indicating that coronals are most frequent in initial position cross-linguistically, including Germanic, Romance, Slavic, Finno-Ugric, and Niger-Congo languages (Janda 1979; cited in Locke 1983). There are also contradictory findings for child-directed speech, with one study indicating that coronals are most frequent word-initially in English and Dutch (Fikkert, Levelt, and van de Weijer 2002) and another claiming that initial labials are most frequent in English, French, and Japanese (de Boysson-Bardies and Vihman 1991). A closer look at these studies explains the apparent contradictions. MacNeilage et al. (1999) did not examine the absolute frequency of initial place features, but rather the relative frequency of Labial…Coronal sequences compared to Coronal…Labial sequences, the former being more frequent in eight of ten languages. The frequency of initial labials in de Boysson-Bardies and Vihman (1991) pertains specifically to place features in the target words attempted by infants in the study, which may be partly determined by children's preferences to attempt sequences within their productive capabilities.

Rather than look to motoric ease or frequency of initial place features as the locus of explanation, we can understand the early acquisition of Labial…Coronal sequences in terms of the constraints and speech planning principles outlined above. Children are likely to acquire the Labial…Coronal sequence first because it conforms to the Non-default…Default preference and does not include the often later acquired [Dorsal] feature. While a Dorsal…Coronal sequence also follows the Non-default…Default pattern and is among the first sequences acquired in some studies (e.g. Menn 1976, Keren-Portnoy et al. 2009), the Labial…Coronal sequence will be easier for children who may have a highly ranked **Not(Dorsal)** or **NotCo-occurring(Onset,Dorsal)** constraint. In addition, it may be preferable to a Labial…Dorsal sequence because the latter requires production of two non-default features in sequence. Bernhardt and Stemberger (1998: 238) suggest that **NoSequence** constraints for two non-default features are often ranked higher than those that include a default feature, e.g. **NoSequence(Labial…Dorsal) >> NoSequence(Labial…Coronal)**.

Some children, like Grace (see also Rose and dos Santos 2006, Vihman and Velleman 1989), may acquire all Labial…Lingual sequences at about the same time, including Labial…Dorsal sequences. Given the favored non-initial position of dorsal in this sequence, this is not surprising. In other children, Labial…Dorsal sequences may be susceptible to anticipatory velar harmony, as attested in Daniel (Menn 1975) and Trevor (Pater and Werle 2003). This is expected if the child derives a ranking of **Not(Dorsal) >> Not(Labial**) (due to the low frequency of dorsals) and consistently preserves the dorsal feature due to the concomitant ranking of **Survived(Dorsal) >> Survived(Labial)**.[103] Perseveratory labial harmony in this sequence is rare except in children who have not yet acquired velars. Metathesis of target Labial…Dorsal sequences is also rare for monolingual English-acquiring children, attested only in a few words (e.g. *difficult* [gɪpɪtul]) during a transient stage of Amahl’s development (Smith 1973), possibly due to a preference for the least frequent feature to appear first in the sequence.

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[103] Velar harmony in this sequence can also be favored by the preference to preserve a final place feature, reflected in the **Priority(Last,C-Place)** constraint.

In the case of Coronal…Labial sequences, both harmony and metathesis tendencies can be explained by the Non-default…Default preference that typically leads to acquisition of Labial…Coronal before Coronal…Labial sequences. This order of acquisition can result in so-called "fronting" metathesis of Coronal…Labial sequences (Ingram 1974, Macken 1978, Jaeger 1997), but only in children who prefer to avoid spreading [Labial] due to a ranking of **SinglyLinked(Labial) >> Linearity**. Anticipatory labial harmony is the more common repair (e.g. Menn 1976, Bernhardt and Stemberger 1998, Fikkert and Levelt 2008, and the present study), due to anticipation of the non-default [Labial] feature. The fact that anticipatory labial harmony typically persists in the absence of perseveratory harmony falls out from the acquisition of Labial…Coronal sequences before Coronal…Labial.

Dorsal…Labial sequences are often among the last sequences acquired (e.g. Macken 1979, Jaeger 1997, Brulard and Carr 2003, Rose and dos Santos 2006, and the present study) and are most prone to metathesis as in *cup* [pʌk]. The presence of two non-default features and the initial position of the dorsal feature contribute to the special status of the Dorsal…Labial sequence. The strong motivation to preserve both non-default features along with the common preference for avoiding an initial dorsal makes metathesis a more likely repair for this sequence than harmony. Alternatively, children may avoid attempting a problematic Dorsal…Labial sequence altogether. This strategy is reported uniquely for Dorsal…Labial sequences for several children: Daniel (Menn 1971) attempted no such sequences from age 1;3 to 2;1; Si (Macken 1979) avoided Dorsal…Labial sequences prior to acquiring Lingual…Labial sequences at age 2;1; and Alice (Jaeger 1997) similarly avoided Dorsal…Labial sequences at age 1;10, to the point of refusing to say *Grandma* and *Grandpa* when asked to do so.

However, at least one child, Trevor, acquired Dorsal…Labial sequences before any other sequence (Compton and Streeter 1977, cited in Pater and Werle 2003). Daniel (Menn 1971, 1975) similarly acquired Dorsal…Labial sequences early, before acquisition of Labial…Dorsal sequences. While not common, this pattern can still be explained in terms of interaction of the speech planning principles and frequency effects. Just as

Non-default…Default sequences are generally preferred in acquisition, a child may favor Dorsal…Labial sequences by virtue of the fact that the less frequent dorsal precedes the more frequent labial feature. Such a preference was discussed above in 4.1.2 as a possible explanation for cases of metathesis of target Labial…Dorsal sequences as in *plastic* [plɑkit] (Smith 1973) and *beaucoup* [kɔpu] (Grammont 1916). Evidence to support this view comes from the fact that Labial…Dorsal sequences were subject to persistent anticipatory velar harmony (e.g. *bug* [gʌg], *pickle* [gɪgʊ]) in Trevor and Daniel's grammars, pointing to anticipation of the least frequent feature, just as there is often anticipation of the non-default feature in Default…Non-default sequences. This acquisition pattern is only viable for children who do not have a problem with production of initial dorsals.

Finally, consider the lingual sequences Dorsal…Coronal and Coronal…Dorsal. Bidirectional harmony is often reported specifically in lingual sequences (e.g. Pater 2002, Smith 1973, Macken 1979, and the present study). This is expected given a potentially high ranking of **Agree(Lingual)**, which may prevent production of any sequence of non-identical lingual articulations. Once this limitation is overcome, Dorsal…Coronal sequences are often acquired first due to the Non-default…Default preference. In English, this common order of acquisition is reflected in the fact that anticipatory velar harmony persists in the absence of perseveratory velar harmony but not vice versa; i.e. only Coronal…Dorsal sequences undergo harmony (Stoel-Gammon 1996). However, acquisition of Coronal…Dorsal sequences before Dorsal…Coronal may occur in children with a relatively high ranking of **NotCo-occurring(Onset,Dorsal)**. As discussed above, a high ranking of this constraint makes target Dorsal…Coronal sequences subject to so-called fronting metathesis rather than harmony, which explains why we do not see harmony persisting only in Dorsal…Coronal sequences.

In addition to explaining common CH and metathesis patterns, the model predicts that certain patterns should be rare or non-existent. The dominance of labial and velar harmony was explained by the fact that labials and velars have a specified place feature (and therefore an applicable **Survived(F)** constraint) while coronals (the default) do not, implying that we should not expect to see coronal harmony. Some apparent counterexamples to this generalization may be due to problems with initial velars (e.g. *cut* [tʌt]) and are therefore not true cases of assimilation. A few children exhibit consistently anticipatory harmony regardless of place of articulation, such as Clara (Rose and dos Santos 2006) and Daniel (Menn 1975). These cases of coronal harmony may be attributed to an undominated **Priority(Last,C-Place)** constraint.

With respect to directionality, we do not expect to see only perseveratory harmony in the absence of anticipatory harmony. Given the preference for Non-default…Default sequences reflected in the ranking **NoSequence(Default…Non-default) >> NoSequence(Non-default…Default)**, Labial…Coronal and Dorsal…Coronal sequences are expected to be acquired first, while Coronal…Labial and Coronal…Dorsal remain susceptible to harmony due to anticipation of the non-default feature. This is the most common pattern reported in the literature. As discussed above, the cases in which Coronal…Dorsal sequences are acquired first are most likely attributable to a ranking of **NotCo-occurring(Onset,Dorsal)** above the **NoSequence** constraints, which leads to metathesis rather than harmony.[104]

We also do not expect to see only bidirectional labial harmony (e.g. *pot* and *top* as [pap]) after sequences of different linguals have already been acquired (as in *cat* and *dog*). Although theoretically the constraints **NoSequence(Labial…Coronal)** and **NoSequence(Coronal…Labial)** could independently be ranked above all other constraints to produce only bidirectional labial harmony, this is extremely unlikely. Bidirectional labial harmony over coronals is expected only in the initial stage when **Agree(C-Place)** is undominated, restricting all place sequences, but is otherwise rare because typically Labial…Coronal is the first sequence acquired. The model includes a **Agree(Lingual)** constraint that may potentially produce bidirectional velar harmony in

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[104] Trevor (Pater and Werle 2003) had perseveratory harmony in Labial…Coronal sequences after some Coronal…Labial sequences were produced accurately. However, his harmony patterns were complicated by consonant-vowel interactions, whereby labial consonants were more likely to co-occur with rounded vowels and velars were more likely to co-occur with back vowels.

lingual sequences only, but there is no comparable constraint that would specifically produce only bidirectional labial harmony, and indeed I have found no reports of bidirectional labial harmony in children who have acquired lingual sequences.

Another pattern predicted to be rare is anticipatory velar harmony over labials in the absence of anticipatory velar harmony over coronals; e.g. *pick* as [kɪk] but *tick* produced faithfully as [tɪk]. If anticipatory velar harmony occurs in a Labial…Dorsal sequence, this is indicative of a speech planning problem in anticipating the least frequent place feature [Dorsal]. If a child incorrectly anticipates the [Dorsal] feature when it follows a labial, we would expect an even stronger tendency to anticipate [Dorsal] in a Coronal…Dorsal sequence such as *tick* as [kɪk] due to the default status of coronals. This expectation is confirmed in the literature reviewed.

Another pattern predicted to be rare is true perseveratory labial harmony over velars, e.g. *pick* as [pɪp] when velars are possible in the child's system. One reason for this is the potential ranking of **Not(Dorsal) >> Not(Labial)** due to the low frequency of dorsals and the concomitant ranking of **Survived(Dorsal) >> Survived(Labial)** necessary for faithful production of these features. Given this ranking, we would expect the labial to assimilate to the velar, preserving dorsal place of articulation. Even if we assume an equal ranking of **Not** constraints against non-default features, the tendency for anticipatory assimilation reflected in **Priority(Last, C-Place)** would still favor velar harmony as in *pick* [kɪk]. Indeed, perseveratory labial harmony over velars is reported only marginally in a single diary study (Cruttenden 1978).[105]

Finally, as discussed in the section on triggers of harmony and metathesis, the model predicts that metathesis of Coronal…Dorsal sequences (e.g. *duck* as [gʌt]) should be extremely rare. Given the tendency to anticipate the non-default feature in a

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[105] The Cruttenden data include two clear examples of labial dominance in *piggy* [pipi] and *bacon* [beɪbən], but also an example of velar dominance in *Grandpa* [gagə]. Interpretation of the data is limited by the fact that only harmonic forms are reported, and no chronological information is provided for the data aside from an age range of 1;6-2;2 for the period studied.

Default…Non-Default sequence, Coronal…Dorsal sequences are likely to be susceptible to harmony. While **NotCo-occurring(Onset,Dorsal)** can trigger metathesis for dorsal-initial sequences, it cannot trigger metathesis of a Coronal…Dorsal sequence. In my review of the literature, metathesis of a target Coronal…Dorsal sequence is reported only for the Hebrew-English bilingual child Shelli (Berman 1977), as in *dog* [gat]. Since this child consistently preferred dorsal-initial sequences, producing metathesis in Labial…Dorsal sequences such as *buggy* [gʌbi] against the typical pattern, this pattern may have resulted from an extension of the Non-default…Default preference as discussed in 4.1.2 combined with a low ranking of **NotCo-occurring(Onset,Dorsal)** and a ranking of **SinglyLinked** >> **Linearity** ruling out harmony as a viable repair.[106]

The present model thus makes valid predictions about the types of CH and metathesis patterns we should expect, but also allows for the variety of patterns attested across children. An apparently unattested pattern is acquisition of Default…Non-default sequences before the reverse, leading to only perseveratory velar or labial harmony or metathesis of Labial…Coronal sequences. This suggests a potentially fixed ranking of **NoSequence(Default…Non-default)** >> **NoSequence(Non-default…Default)** due to universal principles of speech planning, leading to a dispreference for coronal-initial sequences.[107] The seemingly contradictory pattern whereby children prefer to avoid dorsal-initial sequences is nevertheless possible due to the constraint against initial dorsals. The flexibility of this model is therefore preferable to rigid agreement constraints specifying the directionality of harmony as proposed in Pater (2002) and Pater and Werle (2003). By relying instead on constraints against feature sequences and initial dorsals, it has the additional advantage of being able to account for both CH and long-distance place metathesis patterns using the same set of constraints.

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[106] It is also possible that frequency of place features or sequences specific to Shelli's bilingual Hebrew-English input may have influenced her grammar, but in the absence of frequency statistics for the input, I cannot draw any conclusions in this regard.

[107] A stronger claim would be that **NoSequence** constraints do not apply to Non-default…Default type sequences at all. Rather, these sequences may be prohibited only by bidirectional constraints such as **Agree(C-Place)** or **Agree(Lingual)**. This position does seem to be consistent with the data, in that I found no reports of children with only perseveratory velar or labial harmony (in the absence of effects of intervening vowels).

This model is also preferable to analyses that rely on **Alignment** constraints to motivate harmony (Vellemann 1996, Goad 1997[108], Dinnsen and O'Connor 2001) in that it provides principled reasons for typical CH and metathesis patterns, rather than merely stipulating that a place feature should align to a particular word edge. Accounting for bidirectional harmony with **Alignment** constraints is particularly awkward, since it requires stipulating that a place feature such as [Labial] prefers to be aligned both to the left and right edge of a word. The use of **Agree** constraints, on the other hand, provides a natural explanation for bidirectional harmony and explains why it is characteristic primarily of early grammars. As the child learns to plan various feature sequences, **Agree** constraints are demoted, first for the C-Place node and later for the Lingual node, eliminating bidirectional harmony and often leaving only anticipatory harmony in problematic Default…Non-Default type feature sequences. Furthermore, the suggestion in Goad (1997) that the function of CH is to decrease the number of articulatory instructions required in speech production does not follow logically from the use of alignment constraints, but does follow naturally from the view that CH results from constraints on feature sequences and is governed by principles of speech planning.

A final point to make is that I do not appeal directly to the relative frequency of sequences in a given language to explain the occurrence and directionality of CH and metathesis. Thus far, the role of frequency has been limited to determining the default feature value [Coronal] and the least frequent feature [Dorsal] (which may in turn be related to the degree of motor control found in the tip versus the back of the tongue). This differs somewhat from some previous views of metathesis as a process in which uncommon sequences are replaced by more common ones (e.g. Grammont 1933 for child speech, Hume 2004 for adult speech). Rather than attribute metathesis trends directly to frequency, I attribute them to the Non-default…Default speech planning

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[108] Goad's analysis further relies on NOCONTRAST constraints prohibiting underlying forms with "configurations of features that do not conform to the inventory of segments found lexically in a language" (Goad 1997: 135). Such a constraint would contradict the fundamental OT principle of Richness of the Base (Prince and Smolensky 1993).

preference and a constraint against initial dorsals. These considerations may in turn be reflected in the frequency of specific sequences in a given adult language, as observed for Dutch in Fikkert and Levelt (2008), and therefore metathesis may indeed replace less frequent with more frequent sequences.

I leave open the possibility that frequency of specific sequences in the infant's linguistic input may influence the direction of metathesis. If frequency aids in learning, the learner may acquire more frequent sequences first, making metathesis a possible output for a less frequent sequence that has not yet been acquired. For example, Vihman (1978) observes that the three Slavic children in her sample acquired consonant sequences rather rapidly, a fact she attributes to their exposure to a large number of adult forms with consonant contrasts, especially in the diminutive suffix [tʃɛk]. However, frequency of specific sequences in the target language cannot be the primary factor driving CH and metathesis patterns. If it were, CH would not be so prevalent in early acquisition, since harmonic forms are actually relatively low in frequency in many languages (Locke 1983, MacNeilage and Davis 1999, Fikkert and Levelt 2008). For example, English words where both consonants are labial stops such as *beep, bop,* and *boop* are far less common than those with a Labial…Coronal sequence (*cf. beat*, *bit, bait*, *bet*, *bat*, *but*, *bought*, *bite*, *boat, boot*). Locke (1983) suggests that place sharing may be disfavored in fully developed languages due to the propensity for faster rates of speech in mature speakers. In tests of diadochokinetic rates, faster speech rates are possible with sequences of different place of articulation; for example, more syllables per unit may be produced in a sequence such as [pʌtʌkʌ] than in [pʌpʌpʌ] (Lass and Sandusky 1971, cited in Locke 1983). Similarly, MacNeilage and Davis (2000) point to potential problems in both perceptual processing and production with repetition of the same sound at faster rates of speech.

A thorough examination of the effects of language-specific sequence frequency on acquisition must be left to future research. However, we know that the high incidence of CH in children is not attributable to the frequency of harmonic sequences in the adult language, and therefore the explanation must lie elsewhere. While metathesis may result in sequences that are more frequent in the language being acquired, an important contribution of the present model is its ability to provide more principled explanations for the occurrence and directionality of CH and metathesis. Viewed in the context of acquisition of feature sequences, CH is characteristic of early development because children must learn to plan different sequences of features. As shown above, difficulties in sequence production may arise due to the presence and position of the default feature [Coronal], an initial [Dorsal] feature, or a sequence of similar but different lingual places of articulation. The set of constraints proposed here predicts likely orders of acquisition leading to typical patterns, while also being flexible enough to allow for the variety of attested patterns.

4.2.2 The transition from child to adult speech

I have argued that CH and long-distance metathesis emerge in phonological development in the context of the acquisition of consonant sequences, which is governed primarily by constraints on sequences of features. Since these constraints reflect the use of cognitive resources in speech planning and production, they are universal. If this is the case, we need an explanation for the absence of major place feature CH and long-distance metathesis in adult languages. What happens to the constraints that motivate these processes in the course of phonological development? How are CH and long-distance metathesis related to assimilation and metathesis as observed in mature languages?

Stemberger (1996b) and Goad (1997) both suggest that the explanation for the absence of CH in adult languages lies outside the constraints of Optimality Theory. Goad (1997) surmises that CH is eliminated in phonological development for functional reasons. Limitations on place features within a word must be overcome as the child acquires more lexical items and seeks to avoid homophony. This view is compatible with the fact that the sequence constraints in the present model are grounded in the cognitive resources used in speech planning. As children mature, we expect maturation of the cognitive functions involved in planning and executing consonant sequences, which should lead to the elimination of CH. Since sequence constraints also govern long-distance metathesis, this explanation may similarly apply to the elimination of long-distance place metathesis in phonological development.

Stemberger (1996b) attributes the rarity of CH in adult languages in part to diachronic considerations. He observes that many synchronic phonological alternations have their origin in diachronic changes that result from ambiguity of the acoustic signal (see also Blevins 2004). Since consonant-to-consonant transitions across a vowel show relatively little co-articulation, they are not likely to induce the type of diachronic change that would lead to consonant harmony.[109] Diachronic considerations may also help explain the absence of long-distance metathesis of major place features in adult phonology. Hume (2004) attributes patterns of directionality of local metathesis in adult languages to sequence frequency and indeterminacy of the acoustic signal. However, the latter consideration does not appear to be relevant for child language, since long-distance consonant metathesis does not improve perceptual cues, and even very young infants have been shown to be able to discriminate CVC sequences differing in the order of the consonants, such as [pæt] and [tæp] (Bertoncini and Mehler 1981). On the contrary, both CH and long-distance metathesis in child speech involve substitution of a major contrastive feature in a prominent prosodic position, namely the syllable onset (e.g. /dʌk/ [gʌk] for CH; /kʌp/ [pʌk] for long-distance metathesis). The salience of these features in the syllable onset precludes their misperception, making it unlikely that features in these contexts will be susceptible to neutralization in adult speech.

Finally, as alluded to in Menn (2004), the restrictions that CH places on possible contrastive words in the lexicon are arguably too limiting for the expressive needs of human language. Restricting consonant sequences to one place of articulation would require speakers to resort to extreme strategies to expand the lexicon, such as many additional syllables or perhaps an unusually large vowel inventory. It is unlikely that

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[109] Stemberger (1996b) also suggests that high levels of vowel-to-vowel co-articulation contribute to the high occurrence of vowel harmony in adult languages, while it is less common in children. The susceptibility of vowel features to long-distance assimilation may also indicate that vowels carry a lower functional load than consonants, consistent with the observation that "consonants tend to carry more information than vowels" (Boersma 2000).

such a language would evolve when additional permutations of existing consonant place contrasts are available and can be easily learned. This argument could be extended to long-distance metathesis as well. Restricting a major consonant place feature to a single position within a word significantly limits potential expansion of the lexicon. Instead, languages (or the humans who create them) prefer permutation of existing major contrastive features within a word to create additional lexical items. Essentially, we do not see CH or long-distance metathesis of major place features in adult phonology because early limitations on possible place feature sequences in children are gradually overcome in phonological development in order to accommodate the range of contrasts needed in the adult language.

Nevertheless, the feature sequence constraints and speech planning principles that drive CH and long-distance metathesis in children do not simply disappear in the course of phonological development. Although Vihman (1978) does not appeal to constraints, she suggests that adult harmony systems involving minor place features (e.g. sibilant harmony) result from the same kind of processing difficulties that sequences of major place features pose for children. Indeed, the sequence constraints and principles outlined above are evident in both long-distance and local processes in adult phonology.

Sequence constraints for tier adjacency motivate the type of CH that is attested in adult languages; namely, minor place feature harmony. Specifically, **Agree$^{\text{Tier}}$** constraints for the lowest nodes in the place hierarchy, i.e. **Agree$^{\text{Tier}}$(Coronal)** and **Agree$^{\text{Tier}}$(Dorsal),** can produce the coronal and dorsal harmony systems discussed in 3.1.1. This type of harmony is motivated by the desire to avoid sequences of similar elements that are not identical; that is, consonants that share an articulator but differ on a dependent feature, such as [anterior] for coronals and [low] for dorsals. Examples are repeated in (103).

(103) Consonant harmony in adult languages (cited in Rose and Walker 2004)

a. Sibilant (Coronal) harmony in Aari suffix /-**sis**/ (Hayward 1990)
gi**ʔ**-**sis** 'cause to hit' but: naʃ-**ʃiʃ** 'cause to like'

b. Retroflexion agreement in Gimira causative affix /**s**/ (Breeze 1990)
mak 'say' ma**s** 'cause to say'
z̢ert 'be red' z̢er**ʂ** 'make red'

c. Dorsal agreement in Tlachichilco Tepehua prefix /**ʔuks**-/ (Watters 1988)
ʔ**uks**-k'atsa: 'feel, experience sensation'
but: ʔ**oqs**-laqts'-in 'look at Y across surface'

The effects of **NoSequence** constraints that motivate long-distance metathesis can be observed in a rare phenomenon reported by Hyman (2010). Certain Bantu languages have restrictions on the sequences of place features that may appear in triconsonantal verb forms with CVCVC structure. In Tiene, these restrictions result in affixation for some stems but infixation for others. Specifically, C_2 must be coronal and C_3 must be non-coronal, such that expected CVPVT and CVKVT forms (where P=labial, T=coronal, and K=velar) surface instead as CVTVP and CVTVK respectively.

NotTwice constraints prohibiting repetition of the same feature in a sequence (à la the OCP) also have observable effects in adult languages on the consonant tier, as in same-place restrictions in Arabic triconsonantal roots with CVCVC structure (Frisch et al. 2004). Roots with adjacent labial, dorsal, or gutteral consonants are nearly non-existent in the lexicon. Roots with adjacent coronals are similarly rare when matched for manner, meaning that stems with adjacent coronal sonorants, coronal fricatives, or coronal stops are disallowed, while sequences of adjacent coronals are attested if the coronals differ in manner features. The effects of **NotTwice(F)** constraints may also be observed in restrictions on repetition of non-default features in the second and final consonants of CCVC English words (Stemberger and Treiman 1986), as illustrated in (104). Repetition of the default place feature [Coronal] is not similarly dispreferred, permitting words like *state* [steɪt] and *stat!* [stæt].

(104) **NotTwice(Non-default)** constraint in English CCVC words
C_iVC_i sequences allowed: [mam] [pap] [ɹɛɹ] [lʌl]
$C\mathbf{C}_iV\mathbf{C}_i$ sequences disallowed: *[smam] *[spap] *[kɹɛɹ] *[plʌl]

Furthermore, the same principles that govern directionality of CH in children are evident in adult CH systems. Hansson (2001) observes a "palatal bias" in some bidirectional coronal harmony systems, where coronals consistently assimilate to palatals regardless of whether the palatal appears in the stem or affix. This is easily explained in the present model by the bias toward preservation of non-default features reflected in their **Survived** constraints. In addition, the present model provides a principled explanation for the direction of assimilation in certain asymmetric sibilant harmony systems highlighted in Hansson (2001). In these systems, a palatal-initial sequence such as /tʃ…t/ is permitted, but a coronal-initial sequence such as /t…tʃ/ undergoes harmony. This is another reflection of the tendency to anticipate a non-default feature in speech planning, modeled in constraint rankings of the type **NoSequence(Default…Non-default) >> NoSequence(Non-default…Default)**. Interestingly, a similar tendency is observed in the consonant sequences attested in Arabic roots, where among adjacent coronal stop-fricative combinations, the order fricative-stop is much more common than the order stop-fricative (Frisch et al. 2004).

These sequence constraints and speech planning principles are also evident in adult languages for immediately adjacent consonants. Even before the advent of formal constraint-based generative models, Macken observed that CH and non-local metathesis in children obey constraints for non-adjacent consonants "…that closely resemble strict adjacency restrictions in adult languages like…place/manner sequencing constraints on tautosyllabic clusters…" (Macken 1992: 267). In a later article, she states that the differences between child and adult language result from the same constraints operating on different levels: consonant planar adjacency in children, and string adjacency in adults (Macken 1995).

This is formalized in the present model via sequence constraints for both tier and root levels of adjacency. **Agree$^{\text{Tier}}$** and **NoSequence$^{\text{Tier}}$** constraints govern acquisition of consonant feature sequences on the consonant tier, while **Agree$^{\text{Root}}$** and **NoSequence$^{\text{Root}}$** constraints govern the types of sequences allowed in immediately adjacent segments. For example, in English onsets, **Agree$^{\text{Root}}$(Labial)** may rule out *pw and *fp while **NoSequence$^{\text{Root}}$(Labial…Dorsal)** may rule out *pk and *fk. Macken (1995) cites the example of Attic Greek (Steriade 1982), where consonant place sequences in clusters are possible only if the second consonant is coronal. Bailey (1970) similarly observes that constraints in Tagalog require coronals to appear after non-coronals, and that metathesis of word-medial non-coronal+coronal sequences is common cross-linguistically, following the preference outlined above for Non-default…Default sequences. The effects of these constraints may also be seen in phonological processes arising from a language's morphology. In many languages they produce assimilation of adjacent stops, as in Korean /ip+ko/ [ikko] (de Lacy 2002), but they can also result in metathesis, as in Kui /bluk+pa/ [blupka] (Hume 2004).

This progression in phonological development from non-local to strictly local processes can be seen in Grace's longitudinal data. After the acquisition of place sequences across a vowel, CH is eliminated in her outputs. However, place assimilation of two immediately adjacent consonants occurs, as in (105).

(105) Grace, local anticipatory place assimilation (age 1;9-1;11)

knock-knock [nanːak]   *captain* [kætːən]   *picture* [pɪtʃə]
napkin [nækːən]   *Shortcake* [ʃoʊkːeɪk]   *pumpkin* [pʌŋkɪn]

It may also be significant that Grace's acquisition of onset clusters begins only after the elimination of CH; i.e. after she has mastered non-local sequences on the consonant tier. This is true not only of Grace, but of the subjects of other published longitudinal studies. CH and long-distance metathesis are typically reported in child speech only prior to the acquisition of onset clusters. I return to this point in 5.3.2.

A final point of similarity between child speech and adult phonology is that the likelihood of metathesis appears to be greater if two non-default features are involved. In children, we saw that long-distance metathesis was most often reported for Dorsal…Labial sequences. While the default feature [Coronal] more often undergoes harmony, two non-default features are more likely to undergo metathesis due to the desire to preserve these underlying features, modeled in the applicable **Survived** constraints. An example of non-default feature preservation by metathesis for adjacent segments in adult phonology is found in Singapore English. A sequence of obstruents is typically avoided in codas via cluster simplification, e.g. *test* [tɛs], *lift* [lif], *act* [æk] (cf. *testing* [tɛstiŋ], *lifting* [liftiŋ], *acting* [æktiŋ]), but interestingly, an optional rule of metathesis applies only in the case of /sp/ as in *lisp* [lips], where **Survived(Labial)** applies to the /p/ and **Survived(+continuant)** applies to the fricative /s/.

The present model thus helps us understand the role of CH and metathesis in phonological development. Both processes may appear in a child's development as different responses to constraints on feature sequences. Children begin by learning to execute consonant feature sequences on the consonant tier, and thus CH and non-local metathesis affect major place of articulation in child speech. After feature sequences have been acquired on the consonant tier within a speech planning unit, root-adjacent sequences can be acquired. The constraints that motivate CH and non-local metathesis in children remain active in adult phonologies in harmony systems affecting minor place features as well as in local assimilation and metathesis. Furthermore, the same speech planning principles that favor anticipatory consonant harmony in children are evident in adult consonant harmony systems. Finally, the susceptibility of coronals to assimilation in child CH carries over in the bias toward coronal to palatal assimilation in adult sibilant harmony. In this way the model provides continuity of constraints and speech planning principles from child speech to adult phonology.

This model can also help us understand why long-distance metathesis is less commonly reported in phonological development than harmony. While both **Agree** and **NoSequence** constraints can motivate CH, **Agree** constraints can never motivate metathesis, and a **NoSequence** constraint can only cause metathesis if the child has already acquired the reverse sequence and has a relatively low ranking of **Linearity**. Furthermore, **NoSequence** constraints for Default…Non-default type sequences often lead to harmony, not metathesis, due to the lack of a **Survived(Coronal)** constraint and the tendency to anticipate the non-default feature. Metathesis may be triggered by the constraint against initial dorsals, but only for dorsal-initial sequences, and then only if this constraint is ranked above the relevant sequence constraints, as illustrated above. Finally, long-distance metathesis incurs three faithfulness constraint violations for **Linearity** compared to one violation of **SinglyLinked** for harmony. It is therefore not surprising that long-distance metathesis is not as commonly observed as harmony, given the additional faithfulness violations and the limited set of conditions under which it may occur. In Grace's development, for example, metathesis was only attested during a two-month period from age 1;7-1;8, while instances of harmony occurred over a five-month period from age 1;6-1;11. Researchers may actually miss examples of long-distance metathesis in a child's development unless the child is observed longitudinally for a significant period of time.

Finally, the present model leads to an understanding of why CH is common but not universally attested in phonological development. If CH were caused by universal agreement constraints, then it would be somewhat puzzling to find no effects of these constraints in many children. The fact that harmony is not universal is not surprising, however, when it is viewed as only one of several possible responses to constraints on sequences of consonant features. In response to these constraints, children may use a variety of strategies that can change over time, including harmony, metathesis, and lexical selection (avoidance). In Grace's case, lexical selection was evident in her first words, with harmony first appearing at age 1;6 and metathesis at 1;7 after acquisition of Labial…Lingual sequences. Another example of changing strategies comes from Tom, a French-English bilingual child (Brulard and Carr 2003) who showed evidence of an undominated **NoSequence(Dorsal…Labial**) constraint throughout the period studied (from first words to age 2;6). Up until age 2;2, a pure avoidance strategy was used, as he did not attempt any words containing this sequence. At age 2;3, several instances of

Dorsal…Labial metathesis appear, as in *cup* [pɔk] and *compote* /kɔ̃pɔt/[pɔkɔt]. Finally, at age 2;4, he overgeneralizes the common coda consonant [t], resulting in coronal substitution as in *guèpe* /gɛp/ [gɛt], yet another way of avoiding a Dorsal…Labial sequence without resorting to harmony.[110]

We might expect CH to be universal in very early speech due to the **Agree(C-Place)** constraint that often limits first words to one place feature specification. However, I do not claim that this constraint is universally undominated at the onset of speech. Some children may acquire sequences of different place features during the babbling period prior to first meaningful utterances, eliminating the need for CH. Even for children limited initially to one place feature per word, CH may not always be selected as the preferred output, since other strategies are available. Some children may favor lexical selection as a dominant strategy until the relevant consonant sequences have been acquired, depending on their tolerance for unfaithfulness. This was the case for Robin, a Dutch-acquiring child (Fikkert and Levelt 2008), who did not attempt any words with more than one consonant place of articulation in his initial stage of acquisition.

A more drastic strategy for avoiding prohibited consonant sequences is to delete the offending feature or segment altogether. Interestingly, CH and metathesis were not attested in Grace's earliest utterances (age 1;1-1;5), while initial consonant deletion did occur, as in *book* [ʊk] and *fish* [ɪs]. Some children may prefer deletion or avoidance until all sequences have been acquired.[111] Thus while CH is a common occurrence in child speech, it need not be universal. At the same time, constraints on sequences of features are evident in all children's early phonological development, limiting the output in one way or another. Having established the constraints and principles behind CH and metathesis patterns in phonological acquisition, I now turn to a discussion of initial consonant deletion.

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[110] While Tom did exhibit harmony in some words during the period of the study, it was limited primarily to anticipatory velar harmony over coronals.

[111] A fellow linguist reports that his son never produced words with CH, but frequently deleted onsets (Adam Wayment, p.c.).

5 Initial consonant deletion

"…some children even omit initial consonants while retaining them in other contexts. This is just the opposite of what has been observed in fully developed languages."

--Dinnsen and Farris-Trimble (2008: 279)

Children use a variety of strategies to deal with problematic consonants. In a cross-linguistic survey of consonant harmony in thirteen children, some children used assimilation quite extensively, but others relied to a greater extent on deletion (Vihman 1978). For example, 32% of words in one child's data exhibited consonant harmony and 14% had a deleted consonant, while another child's data included only 9% harmonic forms but 36% with deletion. Consonant deletion does not occur with equal frequency in all word positions. For example, Moskowitz (1970) reported that her subject deleted approximately 30% of final consonants at age 2;2, but only rarely omitted medial consonants and never initial consonants. The deletion of final consonants is commonly reported in child speech (Locke 1983, Bernhardt and Stemberger 1998, Bernthal and Bankson 2004).

Initial consonant deletion as in *fish* [ɪʃ] has also been reported in early acquisition, in some cases involving deletion of an entire onset cluster as in *please* [is] (Greenlee 1974), but has received little systematic attention in the literature. As a process, it has been characterized as deviant (Velleman 1998), atypical (Howell and Dean 1994), or idiosyncratic (Stoel-Gammon and Dunn 1985: 159; Velleman and Vihman 2003). Unlike coda deletion, it is unattested in adult phonology. Initial consonant deletion creates an onsetless syllable, while a coda consonant is often preserved. This is unexpected given the frequently cited cross-linguistic preference for CV syllables containing an onset but no coda. In constraint-based approaches, this is reflected in syllable structure constraints mandating onsets but prohibiting codas, as in (106).

(106) Syllable structure constraints (Prince and Smolensky 2004/1993)

ONSET: A syllable must have an onset.

NOCODA: A syllable must not have a coda.

The deletion of a consonant in a stressed syllable in initial position is even more unexpected in light of positional faithfulness considerations, which would normally favor preservation of segments in prosodically prominent positions (Beckman 1998). Given that initial consonant deletion violates both faithfulness and markedness, Velleman and Vihman (2003) conclude that it must result from the emergence of an idiosyncratic child-specific constraint preferring onsetless syllables, perhaps based on a favorite early word or babbling pattern. Dinnsen and Farris-Trimble (2008) consider this phenomenon (and other word-initial errors such as stopping and velar fronting) as evidence for a developmental shift in the assignment of prosodic prominence, hypothesizing that prominence is initially assigned to final position and only later to initial position as observed in adult languages. Grijzenhout and Joppen-Hellwig (2002) propose that initial fricative deletion in German acquisition is motivated by a constraint preferring [-continuant] segments in initial position combined with a ranking of IDENT[CONTINUANT] over MAX-IO (i.e. it is better to delete a segment than to change its feature value for [continuant]). However, the low ranking of MAX-IO they propose for child speech leads them to posit special constraints mandating the presence of at least one consonant and one vowel in every word in order to avoid rampant deletion.

Thus far, explanations for initial consonant deletion have been based on relatively little data. In order to gain a better understanding of the phenomeon, I surveyed studies of early phonological acquisition in multiple languages for reports of initial consonant deletion. Based on this survey, I will show that although it is normally confined to very early development (first 6-10 months of speech), initial consonant deletion is more common in acquisition than previously recognized, and is systematic rather than idiosyncratic. The present case study provides a unique opportunity to analyze initial consonant deletion in the context of the child's grammar as a whole, since Grace's phonological development included instances of initial consonant deletion along with the consonant harmony and metathesis discussed in 3.2. Through a detailed analysis of her longitudinal data, I conclude that it is possible to derive this type of deletion in a constraint-based framework without relying on idiosyncratic or child-specific constraints. Instead, initial consonant deletion results from independently motivated constraints, namely those governing feature sequences and onset sonority preferences. Finally, I discuss reasons why initial consonant deletion is quickly eliminated in the course of phonological development and is not attested in adult phonology.

5.1 Survey of initial consonant deletion in acquisition

5.1.1 Prevalence

Despite its characterization as rare or atypical, there are some indications that initial consonant deletion is more prevalent than previously recognized. In the laboratory context, an experimental study targeting production of difficult segments in novel bisyllabic words by 20 English-acquiring children (ages 1;10-2;4) found that more than half deleted at least one initial consonant, indicating that it is not an uncommon error type (Schwartz and Goffman 1995). However, since the study specifically targeted difficult segments children had not yet acquired and included a large proportion of fricatives and affricates, this high proportion of initial consonant deletion is clearly not representative of its prevalence in normal acquisition.

Children with phonological disorders, who often display error patterns characteristic of much younger typically developing children (e.g. Rockman, Dinnsen, and Rowland 1983; Gierut 1989), are another source of information on the prevalence of initial consonant deletion. Approximately 5% of children in the Developmental Phonology Archive at Indiana University exhibited some initial consonant deletion (Dinnsen and Farris-Trimble 2008). Interestingly, out of the seven phonological disorder case studies discussed in Howell and Dean (1994), three children's error patterns included initial consonant deletion as a process targeted for treatment. Since the case studies were no doubt selected for pedagogical interest, three out of seven should not be taken to represent a typical proportion of children manifesting initial consonant deletion; nevertheless, it illustrates that this process is not exceedingly rare.

Initial consonant deletion in early phonological acquisition is also reported for typically developing children. A study of three children from about 1;0 to the 50-word lexicon stage observes that word-initial consonants may be deleted "when the child is 'working on' another part of the word" (Ferguson and Farwell 1975: 423). Examples from child 'T' include variants of *book*[112] with no initial consonant and *milk* as [ʌk]. At least some instances of initial consonant deletion were found in more than one third of the diary studies of early English acquisition consulted for this survey (e.g. Velten 1943, Waterson 1970, Menn 1971, Smith 1973, Donahue 1986, Ringo 1985[113]), casting its characterization as an atypical process into doubt. This contrasts with coronal backing, another process considered to be atypical by Howell and Dean (1994). While initial consonant deletion is amply attested in the broad sample of acquisition studies in my survey, coronal backing, a truly atypical process, was found in none of them. In a study of phonological processes occurring in 15 typical and 14 lexically-precocious two-year-olds, the incidence of initial consonant deletion was correlated with vocabulary size (Smith et al. 2006). While it was unattested in the lexically precocious two-year-olds, 14% of those with average vocabulary sizes exhibited some initial consonant deletion. While this is a small percentage, it actually exceeds the percentage of average two-year-olds with velar fronting (7%), normally considered to be a common process in child speech.

Initial consonant deletion is reported in studies of early phonological acquisition in many other languages, including Dutch (Fikkert 1994), German (Grijzenhout and Joppen-Hellwig 2002), French (Velleman and Vihman 2003), Spanish (Anderson and Smith 1987, Macken 1978), Italian (Keren-Portnoy et al. 2009) Finnish (Savinainen-Makkonen 2000, Velleman and Vihman 2003), and Hebrew (Bar-Adon 1971, Berman 1977). In a survey of onset cluster acquisition in published diary studies, Greenlee (1974) reports that four of eight children deleted some clusters entirely in their early speech,

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[112] A transcription of *book* is not given, but variation in the initial consonant [b~Ø] is noted.

[113] Although Ringo's dissertation focuses on a child's acquisition of word-initial /s/-clusters, she notes that /l/ and /w/ were omitted not only as the second element of a cluster, but also in word-initial position (Ringo 1985: 177).

including an Estonian child, two French children and one Slovenian child. The incidence of initial consonant deletion may be higher in some languages than in others. In a study of six two-year-olds acquiring Puerto Rican Spanish, initial consonant deletion is reported as one of the processes observed in 25-50% of the data (Anderson and Smith 1987). Three of four Italian-acquiring children followed longitudinally during the first year of speech had instances of initial consonant deletion (Keren-Portnoy et al. 2009). In the Finnish studies, out of a total of 11 children whose data transcription began shortly after they had acquired their first words, all but one had occurrences of initial consonant deletion.

There is some question as to whether all of the examples in the literature constitute true consonant deletion or whether some are actually cases of glottal stop substitution. Unfortunately, since initial glottal stops are frequently ignored and therefore not transcribed in studies of English acquisition, their absence cannot be confirmed in all cases of reported initial consonant deletion. However, since studies have shown that initial pre-vocalic glottal stops are not always present in early acquisition (Bernhardt and Stemberger 1998: 310), it is likely that many of these cases do involve complete segmental deletion rather than glottal stop substitution. At least one acquisition study in German, another language with initial prevocalic glottal stops, specifically notes the absence of a glottal stop in cases of initial consonant deletion (Grijzenhout and Joppen-Hellwig 2002). Reports of initial consonant deletion in languages that do not typically use initial glottal stops (such as French, Italian, and Spanish) provide additional evidence for the occurrence of true initial consonant deletion.

5.1.2 Patterns

Although a wide variety of initial consonants may participate in deletion, not all consonant types are deleted with equal frequency. In addition to noting cases in which initial consonants are deleted, it is equally important to note when they are not deleted. It is not the case that children delete initial consonants across the board or at random; rather, there are certain contexts in which they are omitted. Examples of initial consonant deletion taken from studies of English acquisition are given in (107)a-e., illustrating that initial fricatives and other continuants seem particularly susceptible to deletion, while initial stops are likely to be retained. For example, Amahl deleted only initial /s/ in the earliest recorded stage of his acquisition (Smith 1973).

(107) Initial consonant deletion in English acquisition

a. Joan, age 1;2-1;3 (Velten 1943)
woof/dog [uf] *Fuff* [af] (cat's name) *horse* [us]
cf. no deletion: *pie* [ba] *duck* [dat][114] *push* [bus] *hole* [hu]

b. "P," age 1;6-1;8 (Waterson 1970, cited in Ingram 1989: 358)
fish [ɪʃ] *fetch* [ɪʃ] *vest* [ʊʃ]
cf. no deletion: *dish* [dɪʃ] *brush* [byʃ] *kitty* [tɪti]
cf. harmony*:* *bucket* [bæbuː] *pudding* [pupu]

c. Daniel, age 1;4-2;1 (Menn 1971)
shoes [uz] *sand* [æn] *Steve* [iv] *swing* [ɪŋ]
rake [ejk] *watch* [aʃ] *light* [ajt] *change* [ejndʒ]
cf. no deletion: *night* [najt] *berries* [bejz] *glasses* [gæs]

d. Sean, age 1;3 (Donahue 1986)
water [ɔdu] *hat* [æt] *hello* [ʌwo]
cf. *bye-bye* [baɪbaɪ] *daddy* [dædæ] *dog* [dɔ] *bird* [bœ]

e. Amahl, age 2;2 (Smith 1973)[115]
soup [uːp] *soap* [uːp] *seat* [iːt] *sun* [ʌn] ~ [d̥ʌn]
cf. no deletion: *tent* [d̥ɛt] *park* [b̥aːk] *key* [g̊iː]
cf. harmony: *sing* [g̊ɪŋɪŋ] *sock* [g̊ɔk] *slipper* [b̥ɪbə]

Initial consonant deletion may occur as one of several processes that avoid a particular class of consonants in initial position. In the case of Amahl in(107)e above, initial fricatives were either deleted or underwent consonant harmony. Leonard and McGregor (1991) report on another child 'W' who used a variety of strategies to avoid continuants

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[114] Joan exhibited velar fronting throughout the period of acquisition studied (at least until age 3).

[115] Smith (1973) notes that Amahl's speech had a relatively late onset at age 1;8. Transcription did not begin until age 2;2. Initial /s/ deletion was not consistent (e.g. *soon* [d̥uːn], not [uːn],) and was replaced completely by fricative stopping by age 2;6 (e.g. *soap* [d̥oːp]).

in initial position. She deleted some initial continuants, but interdental fricatives underwent stopping and strident fricatives typically underwent metathesis to final position, provided the target word did not already end in a fricative. Initial stops were produced accurately, as in *go*, *table*, *bib*, *cut*, *night*, etc.

(108) Strategies for initial continuants, 'W', age 2;9[116] (Leonard and McGregor 1991)

a. Initial continuant deletion

look [ʊk]   *ring* [ɪŋ]   *wait* [et]   (BUT: *what* [wʌt][117])
shoes [us]   *five* [aɪf]   *fries* [aɪs]

b. Stopping of initial interdental fricatives

three [di]   *that* [dæt]

c. Metathesis of initial strident fricatives

fall [af]   *full* [ʊf]   *food* [uf]   *fine* [aɪnf]
saw [as]   *six* [ɪks]   *snake* [neks]   *school* [kus]

In children with phonological disorders, similar patterns of initial consonant deletion are attested. Howell and Dean (1994) report on three children whose treatment targets included initial consonant deletion. Barry (4;3) deleted initial fricatives and approximant /ɹ/, while David (age 4;1) deleted initial fricatives and affricates. Both of these children lacked fricatives in their consonant inventory entirely, with stop substitution in other contexts. Jamie (age 4;7) had a more unusual pattern in which initial consonant deletion affected not only voiceless fricatives and affricates, but also voiceless alveolar and velar stops.[118] Stoel-Gammon and Dunn (1985) profile a 5-year-old child with a phonological disorder who used initial consonant deletion in 18% of her possible productions. Again, initial consonant deletion was systematic, affecting only the continuants /l,ɹ,w/ and glottal /h/, while fricatives underwent stopping word-

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[116] W's first words were not produced until 1;10, indicating a possible language delay.
[117] The authors note that W had /w/ in her inventory in initial position, citing the example of *what* [wʌt]. In general, "initial liquids and glides were produced as [w] or omitted" (Leonard and McGregor 1991: 264). It is not clear how frequent initial glide deletion was in her speech, but overall the data point to a tendency to avoid initial continuants, further exemplified in her pronunciation of *swing* as [iŋs] with glide omission.
[118] Jamie realized initial /p/ as as voiced [b].

initially as in *sit* [tʰɪʔ] and were deleted word-finally as in *bus* [bʌ]. A more complex pattern of initial consonant deletion is reported for another child with a phonological disorder who deleted not only initial fricatives and affricates but also initial velar stops, while retaining initial labial stops and palatal glides, as illustrated in (109)a and (b).

(109) Initial consonant deletion in "J," age 4;7 (Gierut 1989)

a. *cup* [ʌp] *cut* [ʌt] *coat* [oʊt] *comb* [oʊm]
sun [ʌn] *soup* [up] *soap* [oʊp] *sock* [aks]
chair [ɛw] *cheese* [iz] *chip* [ɪp]

b. *cf.* no deletion: *boot* [but] *big* [bɪg] *bus* [bʌʃ]
mouse [maʊs] *you* [ju] *yellow* [jɛdoʊ]

Similar patterns of initial consonant deletion are also reported in other languages. Macken (1978) reports that initial consonant deletion was one of several early strategies used by a Spanish-acquiring child to simplify consonant structure. In his earliest productions, "if two consonants co-occurred in a word, they had to agree in place and manner" (Macken 1978: 234). In a few cases, she reports that this was attained by initial consonant deletion, including initial nasals in *mono* 'monkey' [ũnnɔ] and *mira* 'look' [ijə] and the initial fricative in *sopa* 'soup' [hə̥ppo] (actually a case of [h] substitution).

Fikkert (1994) reports that one subject in her study of Dutch phonological acquisition had an early preference for obligatory stop onsets as in *auto* [taːtoː] (age 1;4-1;6), but optionally deleted initial consonants, especially fricatives, from age 1;7 to 1;9.9, as given in (110)a.[119] Initial oral stops, however, were never deleted, as illustrated in (110)b.

(110) Initial consonant deletion in Dutch (Jarmo, 1;7 to 1;9, Fikkert 1994)

a. *vis* [is]~[hiːs] 'fish' *fiets* [iːs] 'bike' *schaap* [aːp] 'sheep'
huis [œys] 'house' *muis* [œys] 'mouse'

b. cf. *daar* [dɑ] 'there' *poes* [puː] 'cat' *maan* [maːn] 'moon'

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[119] Prior to age 1;7, only stop-initial words were attempted.

Grijzenhout and Joppen-Hellwig (2002) report on two German children aged 1;2-1;8 with similar patterns of initial consonant deletion. Naomi's data in (111)a and b illustrate that initial fricatives were subject to deletion, while both oral and nasal stops were produced accurately.

(111) Initial fricative deletion in German (Grijzenhout and Joppen-Hellwig 2002)

a. *Fisch* /fɪʃ/ [ɪç] 'fish' *sauber* /zaʊbɐ/ [abɐ] 'clean'

b. *cf. Brot* [boː] 'bread' *Buch* [buː] 'book' *Milch* [miː] 'milk'

Grijzenhout and Joppen-Hellwig (2002) note that initial fricative deletion and coda deletion appear to be mutually exclusive in the German data. That is, while coda consonants are often omitted in the presence of an initial stop, as in (111)b, they are produced when an initial fricative is deleted as in (111)a. Coda consonants also appear when there is no initial consonant in the target lexical item, as in *ab* [ap^{h}] 'off' and *auf* [af] 'on'. A way of restating the patterns in the German data is that only one consonant place and manner may appear in any given word.

Both final and initial consonant deletion are reported for Shelli, a Hebrew-English bilingual child followed from 1;6-1;11 during the one-word utterance stage (Berman 1977). In her earliest words, final consonants were typically deleted as in (112)a. Exceptions to this rule were two /h/-initial words, where the initial /h/ deleted instead, as given in (112)b. In disyllabic words with no final consonant (i.e. CVCV forms), initial sonorants and fricatives were typically deleted, as in (112)c. With few exceptions, harmonic CVCV forms and initial stops resisted deletion, as shown in (112)d, which includes two examples of fricative stopping where consonants shared place features. However, deletion occurred in early productions of *Bina* [ína], *Tali* [áli], and *doobie* [úbi][120] 'teddy bear' where consonants within the word differed in place and/or manner features. The only deletion in a harmonic form was an initial velar in *cookie* [uki].

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[120] This word later appeared with labial harmony as *doobie* [bubi].

(112) Hebrew-English bilingual data from Shelli, 1;6-1;8 (Berman 1977)[121]

a. Final consonant deletion:

tov [to] 'good'   *ken* [ke] 'yes'   *mocec* [me] 'pacifier'
down [da]   *cat* [ke]   *book* [bo]   *bed* [be]
peach [pi]   *milk* [mə]   *sand* [se]   *soap* [zo]

b. Initial /h/ deletion

hat [et]   *home* [om]

c. Initial sonorant and fricative deletion: (CVCV forms)

Rina [ína]   *Ruti* [úti]   *numi* [úmi] 'lullaby'
Lela [éla]   *Yafa* [áfa]   *Yossi* [ósi]
Shelli [éli]   *Siya* [íya]   *shalom* [alóm] (greeting)
Frankie [eki]   *xuca* [usa] 'outside'   *xam* [am] 'hot'[122]

d. No deletion of initial stops

puppy [papi]   *paper* [pepa]   *baby* [bebi]
buba [bubi] 'doll'   *mama* [mama]   *daddy* [dedi]
pillow [pela]   *kova* [kova] 'hat'   *kise* [kise] 'chair'
safta [tata] 'granny'   *zuzi* [túti] 'move over' (fricative stopping)

Initial consonant deletion was eliminated in most of Shelli's words by about age 1;9, although precise dates are not given (Berman 1977: 17). Berman notes that words with consonant sequences that did not manifest consonant deletion were acquired relatively late during the period studied, i.e. 1;10-1;11 (Berman 1977: 12).

Another study of very early Hebrew language acquisition includes examples of initial consonant deletion during the two-word stage (Bar-Adon 1971). Initial stops and fricatives are unaffected, but initial sonorants /l/ and /r/ are deleted in several words, as in (113).

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[121] Unglossed words are proper names.

[122] Berman notes that Shelli's earliest pronunciation of *xam* was [ha] with final instead of initial consonant deletion, but does not indicate at what age the change took place.

(113) Hebrew acquisition data from "Gila," 1;0-1;3 (Bar-Adon 1971: 438-440)

a. Initial consonant deletion:

Rina [ína] *(A)liza* [iza] *latet* [atet] 'give' *lakum* [akum] 'get up'

b. *cf.* no initial consonant deletion:

buba [búba] 'dolly' *tov* [to] 'good' *kukiya* [kuki] 'cuckoo'

sham [sam] 'there' *sim* [sim] 'put'

Initial consonant deletion is also found in early words for three of the four children in a study of early Italian acquisition (Keren-Portnoy et al. 2009).[123] In contrast to the Germanic languages, however, coda consonants are rare in the Italian data and children attempt primarily disyllabic words. The data in (114)a-c show that deletion affects initial continuants and some initial clusters, while initial stops are retained.

(114) Initial consonant deletion in Italian (Keren-Portnoy et al. 2009)

a. Nina, age 1;8-2;0[124] (Keren-Portnoy et al. 2009)

scarpa [aːpa] *latte* [atːe] *lecca* [ɛkːa] *vino* [awi]

cf. no deletion: *bibi* [bibi] *bimbo* [bibo] *ciuccio* [kukːo]

b. Luca, age 1;2-1;6:

latte [atːe] *rotto* [otːo] *fuoco* [oko] *giochi* [oki]

grazie [atːe] *luce* [utʃe] *piatto* [atːo] *ruota* [ota]

cf. no deletion: *moto* [moto] *casa* [kaza] *bimba* [bimba]

cf. harmony: *caffe* [peːpɛ] *cavallo* [lalːo]

b. Nicola, age 1;6-2;0:

fame [ame] *latte* [atːe] *vieni* [ɛni] *pronto* [onto]

zitto [itːo] *forno* [onːo] *siedo* [edo] *grande* [ande]

cf. no deletion: *papa* [papːa] *bimba* [bimba] *ciao* [tao]

moto [moto] *basta* [bata] *bene* [bene]

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[123] The fourth child in the study was the most advanced talker on three out of four measures of prelinguistic phonetic skill reported in the study, and did not delete any initial consonants.

[124] Nina was a late talker, with only a vocabulary of 71 by age 2;0 (compared to over 350 words for Luca and Anna). Even at the age of two, her restricted consonant inventory included only oral and nasal stops, and all words were limited to one place and manner of articulation.

Studies of Finnish acquisition also provide numerous examples of initial consonant deletion, a fact that is somewhat surprising given the fixed initial stress pattern of the language that might lead us to expect greater faithfulness to initial consonants. In one study, four out of five Finnish children recorded through the 50-word point had instances of initial consonant deletion (Vihman and Velleman 2000-*in Phonological Knowledge*, Velleman and Vihman 2003). Initial consonant deletion was most prevalent in Atte, for whom VCV forms constituted over 60% of his productive vocabulary. In addition to selecting VCV words such as *äiti* 'mom', he deleted initial consonants quite frequently between the ages of 1;5 and 1;8, including some initial stops, as illustrated in (115)a. However, stop deletion did not occur in harmonic forms, as seen in (115)b.

(115) Initial consonant deletion in Atte, acquiring Finnish (*citation*?)

a. *kala* [ala] 'fish' *pallo* [alːo] 'ball' *kello* [ɛlːo] 'clock'
loppu [opːu] 'all done' *sammui* [amːu] 'extinguished'

b. *cf.* no deletion:
kukka 'flower' *mummu* 'grandma' *pappa* 'grandpa'

Savinainen-Makkonen (2000) specifically examined initial consonant deletion in longitudinal data from six Finnish children beginning with their first words, and found that all subjects deleted some initial consonants. Data collection continued at regular intervals until initial consonant omission was eliminated. Five out of the six children ranged in age from 1;3-1;5 at the outset and had eliminated initial consonant deletion by age 2;1. The sixth subject was a relatively late talker whose first words occurred at 1;8 and who persisted in initial consonant deletion until age 2;5. Generally speaking, initial consonant deletion was most frequent in the initial stage, being replaced by other processes as acquisition progressed.[125]

The consonants /h/ and /l/ were most prone to deletion in this Finnish study, although /l/ was produced word-medially by several subjects. There are also examples of initial

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[125] One subject, Pyry, had 90% accuracy of initial consonants attempted in the first session due to the fact that he avoided most consonant-initial words. In subsequent sessions, more consonant-initial words were targeted, resulting in more deletions.

nasal and fricative deletion, as in *maito* [aitoː] ‘milk (partitive)’ (Melina) and *sisko* [ikːo] ‘sister’ (Vinsu). Initial oral stops were rarely deleted. Savinainen-Makkonen observes that consonants were not typically deleted in short words. For example, four of the six subjects first produced word-initial /j/ in /joː/ ‘yes’ (*colloq.*). Initial /n/ was subject to deletion by Vinsu for several months, but not in words like *noin* and *nyt*, as in (116).

(116) Initial nasal deletion in Finnish (Vinsu, Savinainen-Makkonen 2000)
a. *nukkuu* [ukːuː] ‘sleep’ *napa* [apa] ‘navel’ *norsu* [ousu] ‘elephant’
b. *cf.* no deletion: *nenä* [nenæ] ‘nose’ *noin* [noi] ‘this is how’
nyt [nyt] ‘now’ /næːn/ [næːn] ‘I see’ (*colloq.*)

A similar pattern for production of initial nasals was evident in the data for three other subjects. What is striking about this data is that production of an initial consonant is apparently inhibited not just by the length of a word, but specifically by the presence of a different consonant later in the word. That is, the children successfully produce consonant sequences with the same or similar place and manner specifications, but attempts at other target sequences often result in omission of the initial consonant, including some initial velar stops for Sara at age 1;9, as in *kissa* [isːɑ] ‘cat’ and *kassiin* [ɑsːiːn] ‘into the bag’. On the other hand, the presence of the same consonant later in the word facilitated production of an initial consonant. For example, Sara successfully produced initial velar stops in harmonic forms such as *kukka* [kukːɑ] ‘flower’ and *kenkä* [keŋkæ] ‘shoe’. Several of the children successfully produced initial /ʋ/ first in words like *vauva* ‘baby’ and *varvas* ‘toe,’ while it was omitted in words like *vene* ‘boat’ and *vaippa* ‘diaper’.

Savinainen-Makkonen (2000) leaves the question open as to whether omission of initial consonants has its origins primarily in perceptual or productive limitations. However, both Savinainen-Makkonen (2000) and Velleman and Vihman (2003) suggest that initial consonant omission might be common in Finnish children due to the perceptual salience of medial geminates, which draw the learner’s attention to the middle rather than the initial consonant. Indeed, the higher ranking of faithfulness to a geminate consonant may be a relevant factor in the deletion of initial consonants in languages such as

Finnish and Italian. However, the fact that initial consonant deletion is attested in children acquiring a variety of languages that do not have geminates suggests that other factors must be involved.

Patterns of initial consonant deletion similar to those in the Finnish data are also reported for French acquisition, where the absence of glottal stops is specifically noted (Velleman and Vihman 2003). Two out of five French-acquiring children recorded at approximately the 50-word stage for productive vocabulary deleted initial consonants in some target sequences, but successfully produced initial consonants in words with a single place and manner specification, as shown in (117).

(117) Initial consonant deletion in French acquisition (Velleman and Vihman 2003)
a. Marie, 1;7: *chapeau* [apoʰ] 'hat' *merci* [ɛsih] 'thank you'
sur l'eau [eːlːo] 'in the water'
cf. no deletion: *dedans* [dindɔ̃] 'inside' *papillon* [papji] 'butterfly'
b. Charles, 1;3: *lapin* [apɑ] 'rabbit' *chaussures* [ɛdʒo] 'shoes'
chapeau [apo] 'hat' *va pas* [ɑpa] 'doesn't go/work'
cf. no deletion: *maman* [mamã] *papa* [papa]

This survey shows that initial consonant deletion is primarily attested in very early phonological development, typically during the first six to ten months of a child's speech production. In most cases, initial consonant deletion is eliminated by age two, although late talkers may be delayed by several months due to a later onset of meaningful speech. Studies of onset cluster acquisition that include data on cluster deletion (as opposed to reduction) provide additional support for this observation. Greenlee (1974) reports the age of elimination of cluster deletion as 1;6 in a Slovenian child, 1;7 in an Estonian child, and 2;0 and 2;4 for two French children respectively. Studies of English cluster acquisition also indicate that deletion of an entire cluster is rare in children 2;0 and older (Smit 1993) and reported primarily for younger subjects (McLeod et al. 2001). In some cases, an early deletion strategy for an initial consonant may be replaced by substitution in later stages (e.g. Menn 1971, Smith 1973, Grijzenhout and Joppen-Hellwig 2002, and the present study), but never vice versa.

This overview of available initial consonant deletion data also shows that there is systematicity in both the type of consonant that undergoes deletion and the context in which consonants are deleted. Initial fricatives and other continuants are particularly susceptible to deletion, while initial stops are generally preserved, although a few children omit initial velars. Initial consonants followed by a consonant with different place or manner features may also be deleted, while harmonic forms are produced accurately. A constraint-based analysis of this phenomenon should explain why these particular patterns tend to recur across children and across languages.

A successful model should also explain why initial consonant deletion is not attested in adult phonology. In this respect, initial consonant deletion is like consonant harmony and non-local metathesis of major place features. These processes are specific to child speech and are eliminated in the course of phonological development. In the previous section, I demonstrated the link between harmony and non-local metathesis that explains these parallels; namely, that both are tied to the acquisition of consonant sequences within a word. I suggest that like consonant harmony and metathesis, initial consonant deletion can occur as a response to constraints on sequences of features. Constraints governing onset feature preferences also play an important role in determining which initial consonants undergo deletion. The role of these constraints in the emergence and elimination of initial consonant deletion can be illustrated by examining longitudinal data from Grace's phonological development.

5.2 Case study in initial consonant deletion: Grace

5.2.1 Data

In addition to the consonant harmony and long-distance metathesis processes discussed in detail in Chapter 3, Grace also exhibited some consonant deletion. Her earliest utterances (prior to 1;4) are limited to CV(CV) type words, but coda deletion was rare, occurring only in *bread* [bɛ] at 1;2 and only briefly in *boat* [boʊ] at 1;6 before it was produced with harmony as [boʊp]. However, numerous instances of initial consonant deletion are attested from 1;5-1;6, as given in (118)a-c. The initial /h/ deletion pattern is shown in (118)a, where /h/ is deleted when another consonant occurs in the word, but preserved when it is the only consonant. The initial stop deletion pattern is given in (118)b, where instances of deletion contrast with preservation of the initial stop when both consonants in the word share place and manner of articulation. Finally, (118)c shows deletion of a variety of other consonants, especially continuants.

(118) Deletion of word-initial consonants: Grace, age 1;5-1;6
a. Initial /h/ deletion: *help* [ʌʊp] *hat* [ʌʊp]
cf. no deletion: *hi* [haɪ] *hello* [haʊ]
b. Initial stop deletion:
milk [ɛʊk] *book* [oʊk] *blankie* [ʌŋki] *please* [is]
snake [eɪk][126] *duck* [ʌk][127]
cf. no deletion:
cookie [kʊkːi] *baby* [bibi] (*ba)nana* [nænæ][128]
coat [kɔk] *cut* [kʌk] *boat* [boʊp]
c. Deletion of initial [+continuant] consonants:
fish [ɪs] *juice* [ʊs] *snake* [eɪk] *thank you* [ʌŋku]
light [aɪʔ] *read* [iː]

The question remains whether the data here are examples of true segmental deletion or whether glottal stop substitution may have occurred. I transcribed glottal stops in her first word ‘uh-oh’ [ʔʌʔoʊ], but did not transcribe initial glottal stops as a general rule, given that they are predictable in English. Bernhardt and Stemberger (1998: 310) observe that in their experience, English-acquiring children do not necessarily insert initial glottal stops before a vowel in early acquisition. Since I did not focus on this aspect of the transcription, I cannot confirm whether or not glottal stops were present in her vowel-initial words. Given that other researchers have confirmed the absence of glottal stops, however, I proceed under the conservative assumption that glottal stop

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[126] This may be considered either initial nasal or fricative deletion. Although consonant clusters were prohibited during this period, deletion of both members of the cluster is unexpected.

[127] The word *duck* is acquired at the end of this period, just as Grace turns 1;7.

[128] As noted previously in 1.3.1, initial unstressed syllables are omitted throughout Grace’s first year of speech (e.g. *again* [gɛn], *surprise* [paɪs], *giraffe* [jæɸ], *guitar* [taː]).

substitution did not occur and treat these as examples of consonant deletion involving a non-minimal repair,[129] which is the more challenging phenomenon to account for.

It is useful to place the initial consonant deletion data in the context of Grace's overall phonological abilities. Recall that until age 1;6, her words are limited to one consonantal place and manner. This limitation is sometimes respected by vocabulary selection, as in *cracker* [kækʊ] and *baby* [bibi]. Towards the end of this period, at age 1;6, it can also be achieved by consonant harmony, as in *coat* [kɔk] and *boat* [boʊp]. Consonant deletion is another means by which this limitation is respected, since when one consonant is deleted, only a single consonant place and manner remain in the word.

Grace's phonetic inventory is also relevant to understanding the role of deletion in her phonological development. Laterals and English /ɹ/[130] were acquired late, and were therefore completely absent from her productions throughout the period of the study. Although the fricatives [s] and [ɸ] (substituting for labiodental /f/) appear word-finally at 1;6, they are not possible word-initially until 1;9. Similarly, glides appear in diphthongs (e.g. *mouse* [maʊs], *hi* [haɪ]) early on, but not word-initially until much later, with initial /j/ first appearing at 1;9 and initial /w/ not until 1;11.

Initial consonant deletion in Grace's speech is eliminated not all at once, but gradually based on the type of consonant involved. First /h/ deletion is eliminated, with the accurate production of *hop* and *hat* near the end of her 18th month (age 1;6). The deletion of initial stops follows quickly as Grace reaches 1;7 and acquires Labial…Lingual sequences in words such as *splash* [pas] and *bug* [bʌk], eliminating initial stop deletion in *please* [pis] and *book* [boʊk]. Deletion persists slightly longer in *duck*, *snake* and *milk*, which appear by age 1;8 as [dʌk], [neɪk] and [nɪʊk][131] after she acquires Coronal…Dorsal sequences.

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[129] As discussed in , non-minimal repair refers to deletion of a segment in response to a constraint on features, when the minimal repair would constitute a change in the offending feature.

[130] English /ɹ / is treated here as a rounded retroflex glide (Bernhardt and Stemberger 1998: 74).

[131] The substitution of [n] for initial /m/ in *milk* at 1;7 is somewhat puzzling given that Grace had already acquired other Labial…Dorsal sequences (e.g. *monkey* [mʌki]). This may be a rare case of

Deletion of initial fricatives, glides, and liquids persists considerably longer than initial stop deletion. Grace continues to acquire new words with initial consonant deletion from 1;7-1;8, as given in (119), and also substitutes [h] for initial fricatives in some cases, a pattern attested in other children (Bernhardt and Stemberger 1998: 328 for English; Savinainen-Makkonen 2000: 171-172 for Finnish; and Fikkert 1994: 111 for Dutch). Glides are also subject to [h] substitution during this time. At one point, this created a three-way neutralization between *walk*, *rock*, and *sock*, all produced as [hak].

(119) Deletion of word-initial continuants: Grace, age 1;7-1;8

a. *fish* [ɪs] *shoes* [us] *fraise (Fr.)* [ɛs] 'strawberry'
woof [ʊɸ] *wash* [aʃ] *rain* [eɪn] *run* [ʌn] *ride* [aɪt]
luke [uk] *reach* [itʃ] *(mini-)wheats* [its]

b. *cf.* [h] substitution:
watch [hat] *walk* [hak] *rock* [hak] *wipe* [haɪp]
sock [hak] *(raisin)****sec*** [hɛk] *(Fr.)* 'raisin' *sleep* [hip][132]

For a few consonant types, several strategies were used in initial position before the segment was acquired faithfully. In the case of initial target affricates, an early deletion strategy was replaced by stopping. The initial affricate in *juice*, deleted at 1;6, undergoes stopping by 1;8 (*juice* [dus]). The word *chip* [tʌp], acquired just as she turns 1;9, similarly exhibits stopping. Otherwise, no affricate-initial words are attempted until age 1;10, when initial affricates are produced faithfully, as in *change* [tʃẽtʃ]. The only other instance of stopping occurs for initial /l/ in the proper name *Luke*. The progression of Grace's strategies for dealing with /l/ in this context is shown in (120). Deletion is the first preferred strategy, followed by stopping and finally glide substitution once the labio-velar glide [w] has been acquired at age 1;11.

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early misperception, possibly influenced by the following front vowel or the fact that the word usually occurred in the phrase *some milk*. It could also be related to early problems establishing labial nasals, since prior to age 1;6 her only attested labial nasal was labio-lingual (in *mama*).

[132] This word occurs at the end of this period, just after Grace turns 1;9, but just prior to acquisition of initial fricatives.

(120) Progression of strategies for word-initial /l/ in *Luke*
  a. Deletion (age 1;8): [uk]
  b. Voiced stop substitution (age 1;9): [duk]
  c. Glide substitution (age 1;11): [wuk]

Grace's initial consonant deletion is eliminated entirely at age 1;9, when she acquires initial fricatives and her first initial glide /j/ (e.g. *yucky* [jʌki]), which was also used as a substitute for the initial glides /w/ and /ɹ/ as in *wipe* [jaɪp] and *rice* [jaɪs]. Thus as in other children, Grace's initial consonant deletion is limited to a fairly brief period in early acquisition, occurring during an approximately four-month window beginning at 1;5 and ending at 1;9.

Initial consonant deletion affects many types of consonants in Grace's data. Initial [h] deletion is eliminated first, followed by stop deletion, liquid and affricate deletion, and finally initial fricative and glide deletion. Although these deletion processes all affect initial consonants, the fact that they are eliminated at different times for different consonant types indicates that there are different constraints involved. I conclude that for some consonants, deletion is primarily motivated by constraints on sequences of features, while for others it is primarily motivated by onset sonority preferences. The analysis of her longitudinal data bears on several issues in phonological acquisition, including which features are underlying, the nature of faithfulness constraints, and whether learning takes place via constraint demotion or promotion. The relative constraint rankings that account for her error patterns at each stage lead me to conclude that learning proceeds by both demotion of output constraints and promotion of faithfulness constraints. I analyze each deletion type in turn, beginning with her early initial [h] deletion.

5.2.2 Analysis: Deletion in sequences

At 1;5, initial /h/ was deleted in *help* [ʌʊp] and *hat* [æt], but preserved in *hi* [haɪ] and *hello* [haʊ].[133] The obvious difference between these two contexts is the presence of another consonant in the word. Initial /h/ may survive if it is the only consonant in the word, but cannot be produced in sequence with another consonant. At this early stage, in fact, no two consonants with differing place or manner features occur in sequence.[134] Restrictions on sequences of consonant features can be modeled by the **NoSequence** and **Agree** constraints introduced in 2.2.3 and 2.2.4. Recall that **Agree** constraints prohibit a sequence of segments that do not agree in a given feature or feature node, and may be defined for root adjacency or adjacency on the consonant tier. In 3.2.2, I concluded that **Agree(C-Place)** and **Agree(Lingual)** for tier adjacency motivated bidirectional consonant harmony over coronals, since the sharing of consonant features avoids a sequence of segments that differ in that feature. **NoSequence** constraints for tier adjacency such as **NoSequence(Lingual…Labial)** were seen to motivate either harmony or long-distance metathesis, depending on the features involved. However, another way to eliminate a problematic sequence prohibited by **Agree** or **NoSequence** constraints would be to delete one of the segments entirely, eliminating one of the problematic feature nodes in the sequence. Depending on the ranking of various constraints, sequence constraints can sometimes motivate deletion of an initial consonant.

Since initial /h/ deletion occurs in *hat* and *help*, we can conclude that [h] cannot be followed by any other consonant, even a coronal stop with default consonant features. Since glottals have no place features, the problem must lie with the sequence of consonant manner features. While /h/ and stops differ in a number of features, I suggest based on additional data below that a highly ranked **Agree(continuant)**

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[133] I do not address medial /l/ deletion except to note that laterals were not produced until age three and medial coronals were often deleted, e.g. in *Daddy*, *kitty*, *bunny*, *belly*, and *tiny*, possibly in part due to the short duration and low salience of these segments intervocalically.

[134] The one exception to this generalization is that coda-onset sequences differing in nasality were apparently permitted in *blankie* [ʌŋ.ki] and *thank you* [ʌɲ.ku]. As discussed in 3.2.2, sequence constraints may apply in different domains (such as the syllable, the foot), and there is evidence for stronger interactions between consonants within a syllable or occupying the same syllable position in adjacent syllables (i.e. onset-onset sequences).

constraint applies to sequences of consonants within a word (or more precisely a foot, since words are maximally disyllabic at this stage of Grace's development). There are three possible ways of avoiding a violation of this constraint: make the consonants agree, as in [tæt];[135] delete the coda /t/; or delete initial /h/. The fact that initial /h/ deletion is preferred raises two important issues. The first is why the grammar should prefer preservation of the final consonant instead of the initial consonant, especially when the resulting output is an onsetless syllable with a coda. The second is why deletion should be selected as optimal over harmony, when deletion eliminates the entire segment rather than simply the offending feature. The loss of a place feature by harmony seems intuitively preferable to the loss of an entire segment and all of its feature specifications. The minimal repair to avoid violation of a constraint on features would be a featural change rather than segmental deletion. How is a non-minimal repair selected by the grammar?

I first consider the question of why preservation of a coda consonant might be preferred over preservation of the onset. Preservation of the last segment in a sequence recalls the trends for directionality of harmony discussed in 4.1.2. Across children, anticipatory harmony as in *duck* [gʌk] is more common and persists longer than perseveratory assimilation as in *cut* [kʌk]. I argued that the tendency for anticipatory harmony, which preserves the final place of articulation in a sequence of consonants, could be explained by speech planning considerations, which by nature are forward-looking. This was captured in the **Priority(Last, X)** constraint introduced in 2.2.5, which prefers preservation of the features of the last segment in a prosodic domain (such as the syllable or foot). This constraint is only relevant when a sequence constraint prevents both segments of a sequence from being realized. For example, if **Agree(C-Place)** prohibits preservation of both members of a consonant sequence as in *book*, **Priority(Last, C-Place)** would prefer retention of the second consonant, all other things being equal.

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[135] Since English does not permit final [h], I do not consider the harmony candidate [hæh], which would additionally violate the **NotTwice(+continuant)** discussed below, or the metathesis candidate [tæh]), which would additionally incur multiple violations of **Linearity**.

As it turns out, however, all other things are not always equal. In Grace's data, it becomes clear that the particular features of each consonant in the sequence are crucial in determining whether deletion of the initial consonant is optimal. The general insight suggested by her data is that deletion may be preferred when featural changes are deemed to be too unfaithful to justify the production cost. The production of any consonant and its features (both individually and in combination and sequence with other features) requires some degree of effort. The cost associated with production of an unfaithful segment must be weighed against the relative gain. In a constraint-based model, faithfulness constraints motivate production of an underlying segment. If, however, featural faithfulness must be compromised due to constraints prohibiting production of a feature in a given context, and the segment itself is weakly established, it may be preferable to delete the segment altogether rather than produce an unfaithful substitute. How do we derive this type of non-minimal repair in a constraint-based model?

In classic OT (McCarthy and Prince 1995), there appears to be a simple solution based on the fact that IDENT[FEATURE] is only applicable when there is a corresponding segment in the output, but is vacuously satisfied by deletion. Selection of segmental deletion as optimal can be achieved by a ranking of IDENT(FEATURE) over MAX-IO, the constraint against segmental deletion. This is the approach used in Grijzenhout and Joppen-Hellwig (2002), where initial fricative deletion was attributed to a ranking of IDENT[CONTINUANT] >> MAX-IO, making deletion preferable to substitution. This type of ranking for place features can account for initial consonant deletion in *book* as shown in (121), where AGREE(PLACE) prohibits a sequence of place features that do not agree.

(121) Classic OT approach to deletion

/bʊk/	AGREE(PLACE)	IDENT(PLACE)	MAX
a. [bʊk]	*!		
b. [gʊk]		*!	
c. ☞ [ʊk]			*

However, this ranking will always select initial consonant deletion over harmony, which is contradicted in Grace's data for both stops and continuants. Initial continuants are sometimes deleted and sometimes substituted by [h]. Initial stops sometimes undergo deletion, and in other cases harmony. This ranking would make the incorrect prediction for forms like *cut*, where harmony is attested during the same time period as deletion in *book*. As shown in (122), the attested pronunciation in (b) is bolded, but the ranking of IDENT(PLACE) over MAX-IO incorrectly selects the deletion candidate in (c).

(122) Deletion incorrectly selected over harmony

/kʌt/	AGREE(PLACE)	IDENT(PLACE)	MAX-IO
a. [kʌt]	*!		
b. [kʌk]		*!	
c. ☞ [ʌk] ☹			*

In addition, this approach makes no prediction for the progression of strategies for dealing with problematic initial consonants. The faithfulness constraints IDENT[FEATURE] and MAX are in principle freely re-rankable, implying that some children may at first substitute initial consonants and later change to a deletion strategy. This developmental pattern is not attested. Children may progress from deletion to substitution (e.g. Menn 1971, Smith 1973, Grijzenhout and Joppen-Hellwig 2002, and the present study), but not vice versa.

As discussed in 2.2.5, Bernhardt and Stemberger (1998) dispense with IDENT[FEATURE] constraints in favor of **Survived** (cf. MAX[FEATURE]) constraints since the two constraint types are largely redundant, and **Survived** constraints are needed to account for the migration and spreading of non-default features. An advantage of using **Survived** constraints applying independently to a segment's C-Root node, C-Place node, and any contrastive non-default consonant features is that this successfully models the basic intuition that merely changing a feature is more faithful to the underlying segment than deletion of the entire segment, since featural change violates only one constraint (either **Survived(Feature)** if a non-default feature is replaced by a default, or **SinglyLinked(Feature)** if a non-default feature spreads), while deletion violates

Survived(C-Root), **Survived(Place)**, and **Survived(F)** for any contrastive non-default features. A disadvantage to this approach is that it makes it difficult to derive a non-minimal repair in response to a constraint on features, since segmental deletion will always violate more faithfulness constraints than merely changing a feature.

When necessary, Bernhardt and Stemberger (1998) derive non-minimal repairs by relying on a family of faithfulness constraints called **LinkedUpwards**, referring to the premise that all feature nodes must be linked upwards to higher nodes in the structure, including prosodic units, in order to be pronounced. They suggest that sometimes elements are merely de-linked rather than being deleted outright. This allows an element to "survive" in the output even if it is not pronounced, thus avoiding a **Survived** constraint violation. In case of initial stop deletion in *book*, for example, we could assume that the C-Root node and C-Place nodes of the initial consonant are simply de-linked, and that **LinkedUpwards(Root)** is low ranked, allowing these nodes to "survive" even though they are not realized in the output. I prefer not to rely on an abstract distinction between a deleted feature and a de-linked or "floating" feature, since there is no perceivable difference in the output. It seems logical that the absence of a feature in the output should incur a violation of the corresponding **Survived** constraint. As a result, I do not make use of **LinkedUpwards** constraints.

Instead, the data lead me to conclude that a hybrid approach to faithfulness constraints is necessary. Both **Survived** and **Identical** constraints are needed, but serve distinct purposes. **Survived** constraints apply exclusively to the underlyingly specified elements of a segment, including its C-Root node (ensuring the production of consonant root manner features), its C-Place node, if applicable (ensuring that the consonant has place), and any contrastive non-default consonant features of the consonant, such as [Labial], [+nasal], [+continuant], etc.[136] In evaluating violations incurred by deletion of a

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[136] A **Survived(C)** constraint for a consonant's timing unit is also relevant in languages with a length contrast, and occasionally for children who substitute a long consonant for a consonant cluster. However, I found no evidence for its role in Grace's error patterns, and therefore I do not make use of it. One could assume that **Survived(C)** is ranked equally with **Not(C)** in her grammar, such that other constraints determine whether a segment is realized.

segment, only **Survived** constraints are relevant. **Identical** constraints, on the other hand, may apply to predictable non-default features associated with the segment, and are only relevant in evaluating the optimality of possible substitutes. This distinction will become crucial in explaining the deletion and substitution patterns in Grace's data.

Another aspect of the model that will prove crucial in selecting deletion in some cases but not others is default underspecification (Bernhardt and Stemberger 1998), with its implications for the relative ranking of **Not** constraints. As discussed in 2.2.2, default feature values are those that are most frequent (e.g. [Coronal], [+consonantal], and [-nasal] for consonants), while the non-defaults are the less frequent feature value. There are **Not** constraints against all features, since production of any element requires some effort, but **Not** constraints against non-default features are ranked above **Not** constraints against the corresponding default feature; e.g. **Not(-consonantal) >> Not(+consonantal)**; **Not(+nasal) >> Not(-nasal)**, etc., ensuring that default features surface in the absence of any other featural specification. The relative ranking of **Not** constraints (reflecting the effort involved in producing a segment) with respect to the **Survived** and **Identical** constraints for a segment's features will determine whether the segment is worth preserving or is subject to deletion.

While the ranking of **Not(Non-default) >> Not(Default)** is fixed for any given feature, the relative ranking of **Not** constraints against the various non-default features may vary by child. For example, one child may find [+s.g.] segments to be particularly difficult, with highly ranked **Not(+s.g.)** prohibiting [h] and aspirated stops, but have no trouble with velars, while another child may have no trouble with [h] but produce no velars due to highly ranked **Not(Dorsal)**. Based on an extensive analysis of Grace's error patterns, I posit that at age 1;5 (the point at which I begin my analysis), **Not(F)** constraints were ranked in her grammar as in (123). Constraints against default features appear in the lowest stratum, while constraints against non-default features appear in one of two strata above the default features. In particular, constraints against certain non-default aperture features appear to have been ranked higher than constraints against other non-default features. Since codas were amply attested in her early productions, **Not(Coda)** is assumed to be ranked in the lowest stratum.

(123) Relative ranking of **Not** constraints in Grace's grammar

Not(-consonantal), Not(+sonorant)
=====================================
Not(Dorsal), Not(Labial), Not(+continuant),
Not(+nasal), Not(+s.g.), Not(+voice)
=====================================
Not(+consonantal), Not(-sonorant), Not(-continuant),
Not(Coronal), Not(-nasal), Not(Coda)

I hypothesize that **Survived(C-Root)** was ranked above most **Not(Feature)** constraints, helping to preserve nasals and some instances of glottal /h/ despite the non-default manner features of these segments. This also places **Survived(C-Root)** above **Not(Coda)**, consistent with the realization of numerous coda consonants at 1;5. **Survived(Place)** need only be ranked above **Not(Coronal)** in order to ensure that a segment have a place feature, and based on Grace's error patterns, I conclude that it could not have been ranked any higher in the initial stage. I also conclude that **Co-occurring(σ→Onset)** was ranked in the lowest stratum along with **Not** constraints against default features, since onsets were not inserted in vowel-initial words. The relative ranking of these additional constraints is given in (124).

(124) Relative ranking of **Not** and **Survived** constraints in Grace's grammar

Not(-consonantal), Not(+sonorant), **Survived(C-Root)**
===
Not(Dorsal), Not(Labial), Not(+continuant),
Not(+nasal), Not(+s.g.), Not(+voice), **Survived(Place)**
===
Not(+consonantal), Not(-sonorant), Not(-continuant),
Not(Coronal), Not(-nasal), Not(Coda), **Co-occurring(σ→Onset)**

With these rankings in mind, I return to the analysis of initial /h/ deletion. The **Survived** constraints applying to initial /h/ depends on which features we consider to be contrastive and which are predictable. Typically, it is assumed that [+s.g.] is the primary contrastive feature of /h/. Based on this specification, Bernhardt and Stemberger (1998) consider /h/ to be predictably [-consonantal] (as well as [+sonorant] and [+continuant]). However, an extensive analysis of Grace's data leads me to revise certain assumptions about underlying features with respect to /h/ and fricatives.

Voiceless obstruents in English have traditionally been considered to be predictably [+s.g.], the contrastive laryngeal feature in English being [voice] (e.g. Bernhardt and Stemberger 1998, Lombardi 1991, inter alia), but others have argued that aspiration is actually the contrastive laryngeal feature for English (Iverson and Salmons 1995, Avery and Idsardi 2001).[137] In order to make the right predictions for Grace's error patterns, as shown below, I am led to the conclusion that voiceless fricatives were underlyingly specified for [+s.g.] in her grammar, making **Survived(+s.g.)** applicable.[138] This assumption in turn affects the predictability of manner features for glottal /h/. If more than one segment is specified for [+s.g.], manner features are no longer predictable based on this specification. As a result, /h/ must also be specified for [-consonantal] (other aperture features being predictable based on this specification). These assumptions about underlying features will prove crucial in the model's ability to derive Grace's error patterns.

The proposed constraint rankings leading to initial /h/ deletion in *hat* are illustrated in the rather long constraint table in (125). Highly ranked **Agree(continuant)** rules out faithful production of both consonants. While [t] substitution (i.e. harmony) would avoid an **Agree(continuant)** violation, [t] is a poor substitute for /h/ since it does not share any of its features. I hypothesize that [t] is ruled out by **Identical(+continuant)**,

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[137] It is also possible that both [+s.g.] and [+voice] could be specified in a given grammar despite the apparent redundancy this introduces to the system, as recently argued for Swedish (Beckman et al., to appear).

[138] Evidence for [+s.g.] in voiceless fricatives comes from debuccalization of coda /s/ producing [h] in many Spanish dialects, e.g. *estas* [ehtah].

ranked at least as high as **Agree(continuant)** in this stage (consistent with other data explored below). This leaves deletion of one of the consonants as the only option. I attribute deletion of initial /h/ in part to the fact that **Survived(-consonantal)** was not yet ranked above **Not(-consonantal)**, canceling out the effects of these constraints. The additional violations of **Survived(Place)** and **Not** constraints against the non-default features [+continuant] and [+s.g.] incurred by initial /h/ leave preservation of coda /t/ as the optimal output.

(125) Initial /h/ deletion in a sequence

Input: *hat* /hæt/	[hæt]	[tæt]	[hæ]	[æt]
Agree(continuant)	*!			
Identical(+continuant)		*!		
Survived(-consonantal)		*		*
Not(-consonantal)	*		*	
Not(+sonorant)	*		*	
Survived(+s.g.)		*		*
Survived(C-Root)			*	*
Not(+continuant)/Not(+s.g.)	**		**!	
Survived(Place)			*	
Not(Coda)	*	*		*
Not(Coronal)	*	*		*
Not(-continuant)/Not(-sonorant)	**	****		**
Co-occurring(σ→Onset)				*

At the same time, initial /h/ surfaces faithfully when it is the only consonant in the word, since **Agree(continuant)** does not force deletion of one of the segments. Despite the fact that **Survived(-consonantal)** is canceled out by **Not(-consonantal)**, the combined forces of **Survived(+s.g.)** and **Survived(C-Root)** are sufficient to preserve initial /h/, as shown in (126).

(126) Initial /h/ preservation (no sequence)

Input: *hi* /haɪ/	[aɪ]	[haɪ]
Survived(-consonantal)	*	
Not(-consonantal)		*
Not(+sonorant)		*
Survived(+s.g.)	*	
Survived(C-Root)	*!	
Not(+continuant)/Not(+s.g.)		**

Grace's initial stop deletion patterns are similar in that deletion only occurs in underlying sequences of different consonants, as seen in the examples repeated in (127). Deletion of initial oral and nasal stops in (127)a contrasts with harmony in (127)b, where the initial stop is preserved. A successful analysis of initial stop deletion must account for both the deletion and harmony patterns.

(127) Deletion of word-initial stops: Grace, age 1;5-1;6

a) *please* [is] *snake* [eɪk][139] *milk* [ɛʊk]
book [oʊk] *blankie* [ʌŋki] *duck* [ʌk][140]

b) cf. **harmony**: *coat* [kɔk] *cut* [kʌk] *boat* [boʊp]

The fact that stop deletion occurs only in words with different target consonants points to restrictions on consonant feature sequences as the driving force behind this deletion process. I first consider deletion of the initial /p/ in *please*, where the consonants differ in both place and manner. Again, we need to explain why deletion is optimal, and why preservation of the coda consonant is preferred over the initial consonant. The same constraint responsible for initial /h/ deletion, **Agree(continuant)**, is primarily

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[139] I consider both *please* and *snake* to be cases of initial stop deletion. Onset clusters were prohibited in her speech until 1;11. Since she had not acquired laterals or initial fricatives at this point, the cluster should have reduced to the stop (an expectation confirmed by the fact that her pronunciations changed to [pis] and [neɪk] when initial consonant deletion ceased).

[140] The word *duck* is acquired at the end of this period, just as Grace reaches 1;7.

responsible for initial /p/ deletion in *please*, although **Agree(C-Place)** is also applicable. The fact that the final fricative is preserved instead of the labial onset is attributed to a ranking of **Survived(+continuant)** above **Survived(Labial)**, which reflects a generally higher priority placed on preservation of manner features than place features in Grace's grammar.[141] The constraint rankings conspiring to favor initial stop deletion in *please* are shown in (128), where **Agree(continuant)** rules out a stop…fricative sequence, and **Survived(+continuant)** favors preservation of the final fricative.

(128) Initial stop deletion in *please*[142]

Input: *please* /pliz/	[pis]	[tis]	[pi]	[pip]	[is]
Agree(continuant)	*!	*!			
Survived(+continuant)			*!	*!	
Agree(C-Place)[143]	*				
Survived(Labial)		*			*
Survived(C-Root)			*		*
Not(Labial)	*		*	*	
SinglyLinked(Labial)				*	
Not(+continuant)/Not(+s.g.)	**	**			**

Crucially, this same ranking of the applicable constraints selects labial harmony in *boat* at 1;6 as shown in (129).

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[141] **Survived(+continuant)** may have been promoted higher than **Survived(Labial)** in an attempt to acquire initial fricatives, which were prohibited due to onset sonority constraints discussed below.

[142] Since I have already shown that **Co-occurring(σ→Onset)** and **Not(Coda)** are low-ranked and not decisive in selecting the output, I omit these constraints from this and following tables.

[143] Although **Agree(C-Place)** need not be ranked this high to rule out the Labial…Coronal sequence in *please* or *boat*, it does need to be ranked this high to rule out the Labial…Dorsal sequence in *book* (see table in (130) below).

(129) Labial harmony (not deletion) in *boat*

Input: *boat* /boʊt/	[boʊt]	[doʊt]	[oʊt]	[boʊ]	[boʊp]
Agree(C-Place)	*!				
Survived(Labial)		*!	*!		
Survived(C-Root)			*	*!	
Not(Labial)	*			*	*
SinglyLinked(Labial)					*
Survived(Place)				*	

Initial stop deletion in the remaining examples (*book*, *blankie*, *snake*, *milk*, and *duck*) proves somewhat harder to derive. Again, we must explain why deletion is optimal for these words but velar harmony occurs in *cut* [kʌk] and *coat* [koʊk], as well as why final codas are preserved. Even if **Survived(Dorsal)** is ranked higher than **Survived(Labial)**, as shown in (130), this selects velar harmony in *book* rather than attested [oʊk].

(130) Harmony incorrectly selected in *book*

Input: *book* /bʊk/	[boʊk]	[boʊp]	[goʊk]?	**[oʊk]**
Agree(C-Place)	*!			
Survived(Dorsal)		*!		
Survived(Labial)			*	*
Survived(C-Root)				*!
Survived(Place)				*
Not(Dorsal)	*		**	*

Since this constraint ranking fails to select initial consonant deletion, there must be more to the story. It is striking that in all of the instances of initial stop deletion remaining to be explained, the expected repair is anticipatory assimilation to a final velar. While perseveratory velar harmony occurs in words with an initial underlying velar such as *cut*, deletion occurs when the target velar is the last consonant in the sequence. The key generalization is that spreading of [Dorsal] to initial position does not occur, suggesting a dispreference for [Dorsal] in this position. In fact, as discussed at length in 4.1.3, initial velars are problematic for many children, as evidenced by a preference for fronting metathesis and common positional velar fronting patterns in which velars are fronted in initial position but not in codas or medially, e.g. *cook* [tʊk], *cooking* [tʊkɪŋ] (Chiat 1983, Stoel-Gammon 1996, Stemberger 1996a, Dinnsen 2002, Inkelas and Rose 2007). This positional restriction reflects a preference for vowel-like features in rimes and a difficulty in producing the enhanced gesture required for velar closure in a strong prosodic position (see 4.1.3 for additional articulatory justification for this constraint). Bernhardt and Stemberger (1998) use a **Co-occurring(Rime→Dorsal)** constraint to reflect this preference; however, I presented data in 4.1.3 showing that this incorrectly predicts that coronal codas should also be produced as velars in children with positional velar fronting. To avoid this problem, I use a constraint against initial dorsals (following Morrisette et al. 2003; Fikkert and Levelt 2008), formulated as the negative co-occurrence constraint **NotCo-occurring(Onset,Dorsal)**.

This constraint plays a unique role in Grace's grammar, given that she never exhibited velar fronting, initial velars being produced as early as 1;3 in *go*. This implies that **Survived(Dorsal)** must have been ranked above **NotCo-occurring(Onset,Dorsal)**. However, if **NotCo-occurring(Onset,Dorsal)** was ranked above the more general constraints **Not(Dorsal)** and **Not(Labial)**, this would explain why **Survived(Dorsal)** had to be ranked above **Survived(Labial)**. I hypothesize the relative rankings given in for constraints pertaining to non-default place features.

(131) Constraint rankings for non-default place features
Survived(Dorsal)
==================================
NotCo-occurring(Onset,Dorsal), Survived(Labial)
==================================
Not(Dorsal), Not(Labial)

The addition of this constraint to the ranking hierarchy permits perseveratory harmony as in *cut*, where there is an initial underlying [Dorsal] feature, as shown in (132).

(132) Harmony triggered by underlying initial velar

Input: *cut* /kʌt/	[kʌt]	[tʌt]	[kʌ]	[ʌk][144]	[kʌk]
Agree(C-Place)	*!				
Survived(Dorsal)		*!			
NotCo-occurring(Onset,Dorsal)			*		*
Survived(C-Root)			*!	*	
Not(Dorsal)			*	*	*
SinglyLinked(Dorsal)					*
Survived(Place)			*	*	
Linearity			*	*!	

However, adding this constraint to the rankings favors deletion in forms such as *book* where the underlying velar is in *final* position, as shown in (133). Now the choice between initial consonant deletion and velar harmony falls to lower ranked constraints against the production of the initial stop's default features. For ease of comparison, I show only the constraints relevant in deciding between the two candidates in question.

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[144] I consider the metathesis candidate (with coronal deletion) for the sake of completeness, as this would be another way of preserving [Dorsal] feature while avoiding an initial velar. This type of metathesis is attested in "W," who produced *zoo* as [uz] to avoid initial fricatives (Leonard and McGregor 1991).

(133) Deletion of initial consonant when underlying velar is final

Input: *book* /bʊk/	[goʊk]	[oʊk]
NotCo-occurring(Onset,Dorsal)	*	
Survived(C-Root)		*
Survived(Place)		*
Not(Dorsal)	**	*
Not(-sonorant)	**	*
Not(-continuant)	**!	*
Co-occurring(σ→Onset)		*

With this ranking, underlying initial velars are permitted to surface, but an initial [Dorsal] feature cannot surface unfaithfully via feature spreading. In other words, produce an initial dorsal if you must, but better to delete the segment than produce an initial dorsal where it is not called for.

Grace's initial stop deletion and concurrent harmony patterns thus result from the interaction of faithfulness constraints with limitations on consonant feature sequences and a preference for avoiding initial dorsals when they are not underlying. Up until age 1;6, place and manner sequence constraints motivated perseveratory labial and velar harmony in some stop sequences but initial stop deletion in others. The initial rather than the final consonant was preserved in cases of deletion due to constraint rankings placing a higher priority on faithfulness to certain non-default features over others. A summary of the key constraint rankings responsible for Grace's early initial stop deletion is given in (134).

(134) Constraint ranking hierarchy for initial stop deletion, age 1;6

Agree(continuant), Agree(C-Place),
Survived(+continuant), Survived(Dorsal)

====================================

Survived(Labial), Survived(C-Root),
NotCo-occurring(Onset,Dorsal)

====================================

Survived(Place), Not(Labial), Not(Dorsal), SinglyLinked(Place)

Shortly before reaching 1;7, Grace eliminates initial /h/ deletion, permitting acquisition of the additional words *hop* and *hot* with initial /h/. Acquisition of certain initial stops follows shortly thereafter. I suggest that acquisition of initial /h/ in sequences at 1;6 is accomplished by a combination of constraint promotion and constraint demotion. **Survived(-consonantal)** is promoted above **Not(-consonantal)** while **Agree(continuant)** is simultaneously demoted, permitting **Survived(-consonantal)** and **Survived(Place)** to rule out deletion in favor of a faithful pronunciation as shown in (135).

(135) Acquisition of initial /h/ in a sequence

Input: *hat*/hæt/	[hæt]	[tæt]	[hæ]	[æt]
Survived(-consonantal)		*!		*!
Agree(continuant)	*			
Not(-consonantal)	*		*	
Survived(+s.g.)		*		*
Not(+sonorant)	*		*	
Survived(C-Root)			*	*
Not(+continuant)/Not(+s.g.)	**		**	
Survived(Place)			*!	

The demotion of **Agree(continuant)** also aids in the acquisition of initial /p/ in *please*. The first sequence of differing place features produced by Grace occurs in *splash* [pas] just as she reaches 1;7. I suggest that production of the initial labial stop in these examples was also made possible by the demotion and promotion of constraints. **Agree(C-Place)** is demoted while **Survived(Labial)**[145] is promoted, as shown in (136).

(136) Demotion of **Agree** constraints and promotion of **Survived(Labial)**

Input: *please* /pliz/	[pis]	[tis]	[pi]	[pip]	[is]
Survived(+continuant)			*!	*!	
Survived(Labial)		*!			*!
Agree(C-Place)	*				*
Agree(continuant)	*	*			
Survived(C-Root)			*		*

As shown in (137), this also permits production of the initial labial stop in Labial…Dorsal stop sequences, leading to the acquisition of numerous words with this sequence at 1;7 (*bug*, *bag, bike*, *"bonk," monkey*, *broccoli* [baki], etc.).

(137) Acquisition of initial labial in Labial…Dorsal sequence at 1;7

Input: *book* /bʊk/	[boʊk]	[boʊp]	[goʊk]	[oʊk]
Survived(Dorsal)		*!		
Survived(Labial)			*!	*!
Agree(C-Place)	*			
NotCo-occurring(Onset,Dorsal)			*	
Survived(C-Root)				*

---

[145] The fluctuation of these constraints may explain the occurrence of sporadic harmony variants in Dorsal…Labial sequences, otherwise subject to metathesis (as shown in 3.2.2). Perseveratory harmony in *grape* as [kek] at 1;7 follows from a temporary ranking of **Agree(C-Place), Survived(Dorsal)** >> **Survived(Labial)**. Once **Survived(Labial)** was equally ranked with **Survived(Dorsal)**, a later anticipatory harmony variant of *cup* as [pʌp] at 1;8 could result from **Priority(Last,C-Place)** and an unstable ranking of **Linearity**.

The further demotion of **Agree(C-Place)** below **Survived(C-Root)** eliminates labial harmony in Labial…Coronal sequences, also at 1;7. This is shown for *boat* in (129).

(138) Labial…Coronal sequence acquired at 1;7

Input: *boat* /boʊt/	[boʊt]	[doʊt]	[boʊ]	[boʊp]
Survived(Labial)		*!		
Survived(C-Root)			*!	
Agree(C-Place)	*		*	
Not(Labial)	*		*	*
Identical(Lingual)				*
SinglyLinked(Labial)				*!
Survived(Place)			*	

The persistent deletion of initial coronals in lingual stop sequences such as *duck* [ʌk] for a few more weeks can be attributed to **Agree(Lingual)**, which remains highly ranked, despite the demotion of **Agree(C-Place)**.[146] This is shown in the complete constraint table in (139). Coronal…Dorsal sequences are then acquired at 1;8 (e.g. *knock* [nak], *stuck* [tʌk]), indicating that **Agree(Lingual)** has been demoted. Based on additional evidence below, I attribute the acquisition of initial coronals in part to the promotion of **Survived(Place)** around this time.[147] These constraint re-rankings are shown in (140). In the analysis of the remaining instances of initial consonant deletion, I assume that **Survived(Place)** is ranked in the same stratum as **Survived(C-Root)** (effectively making it more difficult to derive these deletions).

---

[146] Details of the initial cluster deletion in *snake*, another Coronal…Dorsal sequence, will be discussed below.

[147] I will argue below that the further promotion of **Survived(Place)** to the highest stratum results in the acquisition of initial fricatives at 1;9.

(139) Persistent deletion of initial coronals due to **Agree(Lingual)**

Input: *duck* /dʌk/	[dʌk]	[dʌt]	[gʌk]	[ʌk]
Agree(Lingual)	*!			
Survived(Dorsal)		*!		
NotCo-occurring(Onset,Dorsal)			*	
Survived(C-Root)				*
Not(Dorsal)	*		*	*
SinglyLinked(Dorsal)			*	
Survived(Place)				*
Not(-sonorant)	**	**	**	*
Not(-continuant)	**	**	**!	*
Co-occurring(σ→Onset)				*

(140) Acquisition of initial coronal stops at 1;8

Input: *duck* /dʌk/	[dʌk]	[dʌt]	[gʌk]	[ʌk]
Survived(Dorsal)		*!		
NotCo-occurring(Onset,Dorsal)			*	
Agree(Lingual) (*demoted*)	*			
Survived(C-Root)				*
Survived(Place) (*promoted*)				*!
Not(Dorsal)	*		*	*
SinglyLinked(Dorsal)			*!	

Interestingly, the timing of these re-rankings can account for a briefly attested instance of anticipatory velar harmony in *doggie* [gagi] at 1;7. If **Survived(Place)** were promoted shortly before the demotion of **Agree(Lingual)**, or if **Agree(Lingual)** remained highly ranked for an onset-onset sequence (see discussion of onset-onset interactions in 3.2.2), anticipatory harmony would be selected in *doggy* prior to the acquisition of Coronal…Dorsal sequences.

(141) Transient anticipatory velar harmony in *doggy* at 1;7

Input: *doggy* /dagi/	[dagi]	[dadi]	[agi]	[gagi]
Survived(Dorsal)		*!		
Agree$^{\text{ONSET}}$(Lingual)	*!			
NotCo-occurring(Onset,Dorsal)				*
Survived(C-Root)			*	
Survived(Place) (*promoted*)			*!	
Not(Dorsal)	*		*	*
SinglyLinked(Dorsal)				*

Grace's early initial /h/ and stop deletion can thus be attributed to **Agree** constraints on both manner and place features. The demotion of **Agree(continuant)**, **Agree(C-Place)**, and finally **Agree(Lingual)** eliminates all instances of initial stop deletion; however, initial continuants continue to be subject to deletion.

5.2.3 Analysis: Initial continuant deletion

Unlike initial stops, is not the case that initial fricatives and glides are produced in some sequences but not others; rather, they never surface at all in initial position until 1;9. This indicates problems with their manner features in initial position rather than in a specific sequence. Initial fricatives are problematic for many children in early acquisition, often subject to stopping (Locke 1983, Fikkert 1994). When not acquired in all contexts simultaneously, fricatives are first acquired word-finally in English (Menn 1971, Ferguson et al. 1973, Edwards 1996, Dinnsen 1996, Bernhardt and Stemberger 1998) and other languages (Brulard and Carr 2003 for a French-English bilingual; Grijzenhout and Joppen-Hellwig 2002 for German; Fikkert 1994 for Dutch). Predominance of fricatives in non-initial position has also been observed in studies of babbling (Redford, MacNeilage, and Davis 1997) as well as in many languages, due to fortition (stopping) processes being common in initial position and weakening (spirantization) processes post-vocalically (Ferguson 1978, Hock 1986: 81).

Brulard and Carr (2003) appeal to a constraint specifically prohibiting word-initial fricatives to account for their late acquisition. Bernhardt and Stemberger (1998) similarly suggest that initial fricatives may be banned by the specific negative co-occurrence constraint **NotCo-occurring(Onset,-sonorant,+continuant)**. However, a constraint specifically designed to prohibit word-initial fricatives may not be necessary, given that fricatives are already disfavored in initial position by onset sonority preferences. Grijzenhout and Joppen-Hellwig (2002) appeal to these preferences in their analysis of initial fricative deletion in German, using a constraint preferring [-continuant] segments in initial position to motivate this process. I assume the full set of onset co-occurrence constraints in Bernhardt and Stemberger (1998), who view onset sonority preferences as emerging from the closed-open cycles of the vocal tract in babbling. The optimal syllabic element or syllable peak has an open vocal tract, while the optimal non-syllabic element has a closed vocal tract. These preferences result in the emergence of the co-occurrence constraints for onsets previously introduced in 2.2.4, repeated in (142).

(142) Constraints governing sonority preferences in onsets

a) **Co-occurring(Onset→ +consonantal**): Onset segments should be [+consonantal].
b) **Co-occurring(Onset→ -continuant**): Onset segments should be [-continuant].
c) **Co-occurring(Onset→ -sonorant**): Onset segments should be [-sonorant].

The predominance of initial oral and nasal stops in Grace's speech and absence of initial fricatives and glides seems to point to **Co-occurring(Onset→ +consonantal**) and **Co-occurring(Onset→ -continuant**) being highly ranked in Grace's grammar. However, as seen above, initial target /h/ surfaces faithfully, and in fact [h] is attested as a substitute for initial continuants, as in *walk*, *rock*, and *sock* all produced as [hak]. This seems to be inconsistent with attributing late acquisition of initial fricatives and glides to onset sonority constraints. Since /h/ is neither [+consonantal] nor [-continuant], it does not conform to these constraints any better than an initial glide.

This inconsistency can be resolved by a slight modification of our understanding of the onset co-occurrence constraints and how they favor vocal tract closure in initial position. The generalization to capture is that if there is a constriction of the articulators serving as the onset of a syllable, this constriction should ideally be as closed as possible. Under this view, /h/ is not subject to onset co-occurrence constraints due to its lack of oral constriction.[148] As a segment whose defining feature is essentially [+spread glottis], /h/ generally surfaces as a voiceless version of the following vowel (Bernhardt and Stemberger 1998: 93). As a result, /h/ should be unaffected by onset sonority constraints, just as it was unaffected by the **Agree(C-Place)** constraint discussed in 3.2.2. in relation to consonant harmony. This suggests that the co-occurrence constraints governing onsets should be restricted to apply only when there is a target oral constriction; that is, when there is an underlying Place node.[149] The onset sonority constraints relevant for Grace's initial consonant deletion are redefined in (143).[150]

(143) Constraints governing sonority preferences in onsets (*modified*)

a) **Co-occurring(Onset→ +consonantal)**:
Onset segments with a target Place node should be [+consonantal].

b) **Co-occurring(Onset→ -continuant)**:
Onset segments with a target Place node should be [-continuant].

---

[148] Glottal /h/ is generally considered to be placeless (e.g. Steriade 1987a, Rice 1992, Stemberger 1993, Parker 2001), although it is argued to have pharyngeal place in some gutteral languages (McCarthy 1994, Rose 1996, Lombardi 2001). In any case, it seems clear that /h/ lacks an oral place of articulation, which seems to be the relevant consideration for onset sonority preferences.

[149] Restricting the constraints to segments with an underlying Place node is necessary to distinguish between /h/ and glides, which are also [-consonantal] but have an oral constriction. The difference could also be captured in the feature [vocalic] used in Padgett (2008) to distinguish vowels and glides, the former being [+vocalic] and the latter [-vocalic]. If this feature system is used, onset sonority constraints could be restricted to [-vocalic] segments.

[150] Redefining the onset constraints in this manner does not affect the constraints that drive glottal stop onset insertion before initial vowels in English. If the grammar requires an onset, a glottal can fulfill this need. A glottal stop will be preferred over [h] in epenthesis because [h] violates **Not[+continuant]**, while a glottal stop violates lower ranked **Not[-continuant]**.

A high ranking of **Co-occurring(Onset→ -continuant**) leads to initial fricative stopping in some children, but never in Grace's speech. Instead, [h] substitution sometimes occurs. As shown in (144), undominated **Co-occurring(Onset→ -continuant**) rules out initial fricatives, while stopping and deletion are ruled out by highly ranked **Survived(+continuant)**. Crucially, [h] satisfies both constraints. Affricate substitution might be another option, since it fulfills both **Co-occurring(Onset→ -continuant**) and **Survived(+continuant)** (assuming a complex segment with both a [-continuant] and a [+continuant] element). However, affricate substitution can be ruled out by a **NotCo-occurring(-continuant,+continuant)** constraint ranked in the same stratum as **Survived(+continuant)**. The grammar selects [h] substitution as optimal because **Survived(Place)** is still not ranked high enough to require a place feature for initial continuants. As suggested above, the grammar places a higher priority on preservation of manner features than place features, making [h] a suitable substitute.

(144) Glottal [h] substitution for initial fricative

Input: *sock* /sak/	[sak]	[tak]	[tsak]	[ak]	[hak]
Co-occurring(Onset→ -continuant)	*!				
Survived(+continuant)		*!		*!	
NotCo-occurring(-cont,+cont)			*!		
Survived(+s.g.)		*		*	
Not(-consonantal)/Not(+sonorant)					**
Survived(C-Root)				*	
Survived(Place)				*	*

However, [h] substitution does not always occur for initial fricatives. Instead, initial fricatives are sometimes deleted—but only in words ending in another fricative:

(145) Initial continuant deletion before a fricative

fish [ɪs] *shoes* [us] *fraise (Fr.)* [ɛs] 'strawberry'

This suggests that another type of sequence constraint may be relevant—one against the repetition of a non-default consonant manner feature within a syllable. The fact that [h] and fricatives both have a [+continuant] feature suggests that **NotTwice(+continuant)** is the relevant constraint.[151] However, adding this constraint to the current hierarchy incorrectly selects stopping as the preferred output due to **Survived(Place)**.

(146) Failure to select initial fricative deletion[152]

Input: *shoes* /ʃuz/	[sus][153]	[hus]	[tus]?	**[us]**
Co-occurring(Onset→ -continuant)	*!			
Survived(+continuant)			*	*
NotTwice(+continuant)	*	*		
Survived(+s.g.)			*	*
Not(-consonantal)/Not(+sonorant)		**		
Agree(continuant)			*	
Survived(C-Root)				*
Survived(Place)		*!		*!?
Not(+continuant)/Not(+s.g)	**	**		

Deriving the deletion of the initial labial fricative in *fish* [ɪs] and Fr. *fraise* 'strawberry' [ɛs] is even more problematic, given that **Survived(Labial)** is also applicable.

---

[151] Another possibility is that it is actually the cumulative effect of repetition of both [+continuant] and [+s.g.]. Indeed, repetition of two non-default features within a syllable seems to be avoided in adult English as well, making fictitious place names such as "Zuz" and "Thoth" sound odd or foreign. In each case, two non-default features are repeated: [+continuant] and [+voice] in the former, and [+continuant] and [+distributed] (or interdental) in the latter.

[152] Constraint violations are marked for initial consonants only for ease of comparison.

[153] Since all final obstruents are devoiced at this stage of Grace's grammar, I do not consider the fully faithful candidate [ʃuz].

(147) Failure to select initial labial fricative deletion[154]

Input: *fish* /fɪʃ/	[fɪs]	[hɪs]	[pɪs]?	[ɪs]
Co-occurring(Onset→ -continuant)	*!			
Survived(+continuant)			*	*
Survived(Labial)		*		*!
NotTwice(+continuant)	*	*!		
Survived(+s.g.)			*	*
Not(-consonantal)/Not(+sonorant)		**		
Agree(continuant)			*	
Survived(C-Root)				*
Survived(Place)		*		*

Since fricative stopping is unattested in Grace's speech, the generalization seems to be that a [-continuant] segment is never an acceptable substitute for an underlyingly [+continuant] consonant. However, if **Survived(+continuant)** were ranked any higher, then initial fricatives would in fact be possible. This suggests that **Identical** constraints are involved. As discussed in 2.2.5, I consider **Survived** constraints to reflect the strength of the connection to an underlying feature in the lexicon, while **Identical** constraints evaluate a potential output segment's identity to non-default features associated with the target segment, reflecting the child's view of how much a potential substitute "sounds like" the target consonant. Since stops are never a viable fricative substitute for Grace, this suggests that **Identical(+continuant)** is undominated. Allowing **Identical(+continuant)** to be ranked above **Survived(+continuant)** correctly selects deletion of an initial fricative when followed by a continuant due to the additional **Not** constraint violations incurred by [h]. [155]

---

[154] Constraint violations are marked for initial consonants only for ease of comparison.

[155] Interestingly, Joan (Velten 1943) deleted initial /h/ in *horse* when also deleting initial consonants in *woof* and *Fuff* (cat's name), suggesting a high ranking of the same constraint.

(148) Initial fricative deletion in a sequence of continuants[156]

Input: *fish* /fɪʃ/	[fɪs]	[hɪs]	[pɪs]	[ɪs]
Identical(+continuant)			*!	
Co-occurring(Onset→ -continuant)	*!			
Survived(+continuant)			*	*
Survived(Labial)		*		*
NotTwice(+continuant)	*	*		
Survived(+s.g.)			*	*
Not(-consonantal)/Not(+sonorant)		**		
Survived(C-Root)				*
Survived(Place)		*		*
Not(+continuant)/Not(+s.g)	**	**!		

It is important to note that underlying initial /h/ was permitted during this time in [+continuant] sequences as in *house* [haʊs] and *horse* [hoʊs]. The generalization seems to be that a [+continuant] sequence should be avoided unless both features are underlying. A likely explanation for preservation of initial underlying /h/ in this context is that by this time, **Survived(-consonantal)** had been promoted above **Survived(+continuant)**. This is not unexpected, since promotion of this constraint would be necessary to acquire initial glides. While this constraint has no effect on initial underlying fricatives, it saves initial underlying /h/, as shown in (149).

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[156] Constraint violations are marked for initial consonants only for ease of comparison.

(149) Preservation of underlying initial /h/

Input: *house* /haʊs/	[aʊs]	[haʊs]
Survived(-consonantal)	*!	
NotTwice(+continuant)		*
Not(-consonantal)		*
Not(+sonorant)		*
Survived(+s.g.)	*	

An interesting result of the constraint rankings discussed thus far is that they permit an explanation for one of the few regressions in her data. At 1;5, an initial affricate was produced in *cheese* [tsis], which remained stable for over a month. At 1;7, however, the affricate was lost as she changed her pronunciation to [kis].[157] Given the high ranking of **NotCo-occurring(-continuant,+continuant)** and **NotTwice(+continuant)** discussed above, it is surprising that an initial affricate was viable so early on, especially in a sequence of [+continuant] segments. However, the rankings established thus far can account for this if we assume that affricates have a branching [continuant] feature specification consisting of a [-continuant] portion followed by a [+continuant] portion, making both **Survived(-continuant)** and **Survived(+continuant)** applicable (see Bernhardt and Stemberger 1998: 330-331 for discussion).[158] As shown in (150), when **Agree(continuant)** is highly ranked at 1;5, **Survived(C-Root)** rules out deletion and **Survived(+s.g.)** rules out stop substitution (since aspiration had not yet been acquired on stops). After the demotion of **Agree(continuant)**, however, [kis] becomes optimal.

---

[157] The choice of a velar rather than a coronal stop may indicate an underlying [Dorsal] feature in her affricate or possibly the palatalizing influence of the following high vowel, given her pronunciation of *deer* as [gi] at the same age.

[158] Both feature values must be specified (and therefore subject to **Survived** constraints), since no specification would insert only default [-continuant], resulting in a stop, and only specifying [+continuant] would result in a fricative rather than an affricate (an error pattern I have observed in a 9-year-old with a phonological delay, producing *chair* [ʃɛə] and *Charlie* [ʃali]).

(150) Initial affricate in *cheese* at 1;5-1;6

Input: *cheese* /tʃiz/	[tis][159]	[his]	[is]	[tsis]
Agree(continuant)	*			
NotTwice(+continuant)		*		*
NotCo-occurring(-cont,+cont)				*
Survived(+continuant)	*		*	
Survived(-continuant)		*	*	
Survived(C-Root)			*!	
Not(-consonantal)/Not(+sonorant)		**!		
Survived(+s.g.)	*!		*	

(151) Stop substitution in *cheese* at 1;7[160]

Input: *cheese* /tʃiz/	[kis]	[his]	[is]	[tsis]
NotTwice(+continuant)		*		*
NotCo-occurring(-cont,+cont)				*!
Survived(+continuant)	*		*	
Survived(-continuant)		*!	*!	
Agree(continuant)	*			
Survived(C-Root)			*	
Not(-consonantal)/Not(+sonorant)		**		
Survived(+s.g.)	*		*	

---

[159] Since sequences of different lingual features were not permitted during this time, I consider only coronal stop substitution (as opposed to velar).

[160] This assumes that highly ranked **Identical(+continuant)** does not apply to affricates, given conflicting manner specifications of both [-continuant] and [+continuant].

Finally, I turn to the substitution and deletion of initial glides, which violate both **Co-occurring(Onset→ -continuant**) and **Co-occurring(Onset→ +consonantal**). Given the implications of default underspecification discussed in 2.1.1, since glides are underlyingly [-consonantal] and predictably [+continuant], **Survived(-consonantal)** applies but **Survived(+continuant)** does not. However, since I consider predictable non-default features to be subject to **Identical** constraints, **Identical(+continuant)** does apply. I first consider a scenario in which **Co-occurring(Onset→ +consonantal**) is at the top of the hierarchy and **Survived(-consonantal)** has not yet been promoted above **Survived(+continuant)** (proposed to account for initial /h/ preservation in *house* and *horse* at age 1;8). The interaction of these constraints is shown in (152) for *wipe*, where **Co-occurring(Onset→ +consonantal**) rules out an initial glide. Highly ranked **Identical(+continuant)** rules out stop substitution, and initial [h] substitution is preferred over deletion because it satisfies **Survived(-consonantal)**.

(152) Initial glide substitution by [h]

Input: *wipe* /waɪp/	[waɪp]	[baɪp]	[aɪp]	[haɪp]
Co-occurring(Onset→ +consonantal)	*!			
Identical(+continuant)		*!		
Co-occurring(Onset→ -continuant)	*			
Identical(+sonorant)		*		
Survived(Labial)/Survived(Dorsal)[161]		*	**	**
Survived(-consonantal)		*	*!	

I next consider a scenario in which **Survived(-consonantal)** has been promoted by one stratum, proposed above to account for preservation of underlying initial /h/ in *house*.

---

[161] Both **Survived(Labial)** and **Survived(Dorsal)** apply since the underlying labio-velar glide has two place features.

(153) Initial glide substitution by [h] with promotion of **Survived(-consonantal)**

Input: *wipe* /waɪp/	[waɪp]	[baɪp]	[aɪp]	[haɪp]
Co-occurring(Onset→ +consonantal)	*!			
Survived(-consonantal)		*!	*!	
Co-occurring(Onset→ -continuant)	*			
Identical(+sonorant)			*	
Survived(Labial)/Survived(Dorsal)		*	**	**

This ranking predicts that [h] substitution will always win, since it is the only viable way of satisfying **Survived(-consonantal)**. However, recall that [h] substitution for initial glides was not consistently attested. How do we account for deletion in *woof*, *rain*, *ride,* and *run* at 1;7-1;8, and even in *wake, reach* and *wash* just prior to the acquisition of initial fricatives? Early glide deletion in *woof* could be attributed to **NotTwice(+continuant)** prior to the promotion of **Survived(-consonantal)**, as seen above for initial fricative deletion in similar sequences, but this does not explain the other deletions. One possible reason for the variability in [h] substitution for initial glides is the applicability of **Identical(+voice)**. While [h] is a good substitute for a voiceless fricative since it is also [+s.g.], the fact that [h] is not voiced makes it a less than ideal substitute for a glide.[162] If **Identical(+voice)** fluctuated in ranking, but was sometimes ranked as high as **Survived(-consonantal)**, it would prevent [h] from being optimal.

This scenario for deletion of initial glides is shown in (154), where all relevant constraints are listed, including place co-occurrence constraints. The palatal glide /j/ violates **Co-occurring(Coronal,Dorsal)**, while labio-velar /w/ violates **Co-occurring(Labial,Dorsal)**. There is reason to believe that the latter constraint was ranked higher, since /j/ was acquired a full month before /w/. This is expected since constraints against the co-occurrence of two non-default features are often ranked higher

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[162] No initial voiced fricatives were attempted during this time period, so [h] substituted only for initial voiceless fricatives.

than co-occurrence constraints involving a default feature, as discussed in 2.2.2. With the addition of these constraints and a high ranking of **Identical(+voice)**, deletion becomes the optimal output.

(154) Initial glide deletion

Input: *wake* /weɪk/	[weɪk]	[beɪk]	[jeɪk]	[eɪk]	[heɪk]
Co-occurring(Onset→ +consonantal)	*		*		
Survived(-consonantal)		*		*	
NotCo-occurring(Labial,Dorsal)	*!				
Identical(+continuant)		*!			
Identical(+voice)					*
Co-occurring(Onset→ -continuant)	*		*!		
Survived(Labial)			*	*	*
Survived(Dorsal)		*		*	*
NotCo-occurring(Coronal,Dorsal)[163]			*		
Survived(C-Root)				*	
Survived(Place)				*	*
Not(-consonantal)/Not(+sonorant)	**		**		**!

To summarize, I conclude that the constraint hierarchy in (134) is responsible for the Grace's deletion and substitution patterns for initial fricatives and glides.

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[163] Note that this constraint does not prevent off-glides from surfacing as in *car* [kaj] and *door* [doj] at 1;8, since **Co-occurring(Onset→ +consonantal)** does not apply in this position.

(155) Constraint rankings for initial fricative and glide error patterns, age 1;7-1;8

Co-occurring(Onset→ +consonantal), Co-occurring(Onset→ -continuant),
Survived(-consonantal), Identical(+continuant), Identical(+voice)

===

NotTwice(+continuant), Survived(+continuant),
Survived(Labial), Survived(Dorsal), Identical(+sonorant)

===

Survived(+s.g.), Survived(C-Root), Survived(Place),
Not(-consonantal), Not(+sonorant)

The acquisition of initial continuants begins at 1;9, when Grace produces her first initial fricative in the word *see*. Note that the demotion of **Co-occurring(Onset→ -continuant**) is not sufficient to select an initial fricative, since [h] substitution still avoids a violation of this constraint.[164] However, if **Survived(Place)** is also promoted, [h] is no longer optimal, as shown in (156).

(156) Acquisition of initial fricatives

Input: *see* /si/	[si]	[ti]	[i]	[hi]
Identical(+continuant)		*!		
Co-occurring(Onset→ -continuant) (*demoted*)	*			
Survived(+continuant)		*	*	
Survived(Place) (*promoted*)			*!	*
Survived(C-Root)			*	
Survived(+s.g.)		*	*	
Not(-consonantal)/Not(+sonorant)				**!

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[164] Acquisition of initial fricatives cannot be attributed instead to the promotion of **Survived(+continuant)** because this would predict survival of the fricative from this point forward in all of Grace's initial cluster reduction. This was not the case, as discussed in 6.2.2.

Assuming the promotion of **Survived(Place)** at about 1;9 has the additional advantage of explaining the progression of error patterns for the initial /l/ in *Luke*. Very few initial laterals were attempted, but prior to 1;9 they were deleted in *light* [aɪʔ] (1;6), *Luke* [uk] (1;8), and Fr. *au lit* /o li/ 'in bed!' [o.i] (1;8). To derive initial /l/ deletion, we need only assume that **Not(+lateral**) was ranked in the highest stratum, above **Survived(+lateral)**. Since other features of /l/ are predictable based on [+lateral], no other **Survived(F)** constraints apply, and the constraint rankings already established above result in initial /l/ deletion, as shown in (157). Stop substitution is ruled out by **Identical(+sonorant)** (which must be ranked above **Not(+sonorant)**), and [h] substitution is ruled out by constraints against non-default features, resulting in deletion being selected as optimal.

(157) Deletion of initial /l/ at 1;8

Input: *Luke* /luk/	[luk]	[duk]	[huk]	[uk]
Not(+lateral)	*!			
Survived(+lateral)		*	*	*
Identical(+sonorant)		*!		
Survived(Place)			*	*
Survived(C-Root)				*
Not(-consonantal)/Not(+sonorant)			**!	

By age 1;9, however, Grace produced *Luke* with an initial stop as [duk]. This is expected given the promotion of **Survived(Place)** associated with acquisition of initial fricatives, if we assume that **Identical(+continuant**) does not apply to /l/ in her lexicon. Bernhardt and Stemberger (1998: 700) note that /l/ may be considered either [+continuant] or [-continuant], depending on the definition of [+continuant]. If only airflow through the oral cavity is relevant, then /l/ is [+continuant]. However, if airflow over the constriction matters, /l/ is [-continuant] since there is closure at the constriction, permitting airflow only over the sides of the tongue (see Chomsky and Halle 1968). The value of [continuant] for laterals may therefore vary depending on the child, just as laterals vary in their behavior cross-linguistically, patterning with continuants in some languages but with non-continuants in others (Mielke 2004). Since Grace considered [d] a good substitute for /l/ despite a high priority placed on faithfulness to [+continuant] elsewhere, I conclude that she considered it to be [-continuant].[165] Given this assumption, the promotion of **Survived(Place)** leads straightforwardly to [d] substitution for initial /l/.

(158) Stop substitution for initial /l/ at 1;9

Input: *Luke* /luk/	[luk]	[huk]	[duk]	[uk]
Not(+lateral)	*!			
Survived(+lateral)		*	*	*
Identical(+sonorant)			*	
Survived(Place) (*promoted*)		*		*
Not(-consonantal)/Not(+sonorant)		**!		
Survived(C-Root)				*!

Promotion of **Survived(Place)** also sets the stage for the acquisition of initial palatal glides at 1;9 shortly after Grace produces her first initial fricative. Once **Survived(Place)** has been promoted, demotion of **NotCo-occurring(Dorsal,Coronal)** makes initial [j] possible, both for underlying /j/ as in *yucky* [yʌki] and as the optimal substitute for initial /w/ and /ɹ/.[166] This is shown in (159) for [j] substitution in *wipe* at 1;9. With this development, initial consonant deletion is eliminated in Grace's speech.

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[165] Alternatively, like affricates, /l/ could be considered both [+continuant] (over the sides) and [-continuant] (over the middle). In either case, **Identical(+continuant)** would not apply.

[166] Initial /w/ is finally acquired at 1;10, which could be modeled either by the demotion of **NotCo-occurring(Labial,Dorsal)** or the promotion of **Survived(Labial)** or **Survived(Dorsal).**

(159) Initial [j] acquisition

Input: *wipe* /waɪp/	[waɪp]	[baɪp]	[aɪp]	[haɪp]	[jaɪp]
Co-occurring(Onset→ +consonantal)	*				*
Survived(-consonantal)		*	*		
Identical(+continuant)		*!			
Identical(+voice)				*	
NotCo-occurring(Labial,Dorsal)	*!				
Co-occurring(Onset→ -continuant)	*				*
Survived(Labial)/Survived(Dorsal)			**	**	*
Survived(Place)		*	*!	*!	
Not(-consonantal)/Not(+sonorant)	**			**	**
NotCo-occurring(Dorsal,Coronal)					*

One exceptional case of initial consonant deletion remains to be addressed; namely, deletion in *juice* [us] at 1;6. Unlike *cheese* [tsis], where the initial affricate was produced at this age, *juice* is an isolated case of initial affricate deletion. One difference between the words is that under the assumptions of this model and the feature specifications posited for Grace's grammar, **Survived(+s.g.)** applies for the voiceless affricate in *cheese*, but not for the voiced affricate in *juice*. Nevertheless, given the rankings established above in (150) for *cheese*, deletion in *juice* is unexpected. As shown in (160), it appears that the constraint rankings should select either an initial affricate or stop substitution instead of the attested deletion.

(160) Failure to select initial affricate deletion in *juice* at 1;6

Input: *juice* /dʒus/	[dzus]?	[hus]	**[us]**	[dus]?
Agree(continuant)				*
NotCo-occurring(-cont,+cont)	*			
Survived(+continuant)			*	*
Survived(-continuant)		*	*	
NotTwice(+continuant)	*	*		
Survived(C-Root)			*!	
Survived(Place)		*!		
Not(-consonantal)/Not(+sonorant)		*		

The fact that an affricate+fricative sequence was possible in *cheese* [tsis] but not *juice* *[dzus] or *[tsus] (since voicing was not yet established in obstruents) points to the vowel as a possible source of the difference. As discussed in 3.2.2, there was evidence for consonant-vowel interactions in Grace's grammar. Perserveratory velar harmony persisted in Dorsal…Coronal sequences with a back vowel such as *coat* [koʊk], which I suggested was due to an **Uninterrupted(Dorsal)** constraint that favors sharing of the [Dorsal] feature across the whole word. A similar constraint, **Uninterrupted(Coronal)**, could be responsible for the difference between the initial affricate in *cheese* [tsis] but not in *juice* [us]. With the front vowel in *cheese*, both consonants and the vowel share [Coronal], while this is not the case with the back vowel in *juice*. Adding this constraint to the hierarchy, initial affricate deletion is selected as optimal, as shown in (161).[167] At age 1;8, however, stop substitution in *juice* as [dus] became the preferred output, pointint to demotion of **Uninterrupted(Coronal)**, as given in (162).

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[167] This implies that Grace placed a higher priority on faithfulness to the vowel's features than the consonants; otherwise she could have changed the vowel in *juice* to a front vowel in order to satisfy **Uninterrupted(Coronal)**. I do not consider such a candidate in the constraint table, but assume that higher ranked faithfulness constraints for vowel features would rule it out.

(161) Initial affricate deletion in *juice* at 1;6 due to **Uninterrupted(Coronal)**

Input: *juice* /dʒus/	[dzus]	[hus]	[us]	[dus]
Agree(continuant)				*
NotCo-occurring(-cont,+cont)	*			
Survived(+continuant)			*	*
Survived(-continuant)		*	*	
NotTwice(+continuant)	*	*		
Uninterrupted(Coronal)	*!			*!
Survived(C-Root)			*	
Not(-consonantal)/Not(+sonorant)		**!		
Survived(Place)			*	

(162) Stop substitution in *juice* at 1;8

Input: *juice* /dʒus/	[dzus]	[hus]	[us]	[dus]
NotCo-occurring(-cont,+cont)	*			
Survived(+continuant)			*	*
Survived(-continuant)		*	*!	
NotTwice(+continuant)	*!	*!		
Survived(C-Root)			*	
Survived(Place) (*promoted*)[168]		*	*	
Not(-consonantal)/Not(+sonorant)		**		
Agree(continuant)				*
Uninterrupted(Coronal) (*demoted*)	*			*

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[168] By this time, **Survived(Place)** had been promoted to aid in the acquisition of initial stops in Coronal…Dorsal sequences; however, this does not affect the output in this example.

To review, initial consonant deletion in Grace's phonological development did not have a single underlying cause; rather, the interaction of several factors led to deletion of different consonant types in initial position at different points in time. Limitations on sequences of different consonant features (modeled by **Agree** constraints) were the primary motivation for both early initial /h/ deletion and initial stop deletion. The fact that initial /h/ was problematic only when followed by a stop as in *hat* suggested a high ranking of **Agree(continuant)**. A combination of factors led to initial /h/ deletion being preferred over stop substitution or coda stop deletion. A high priority placed on faithfulness to [+continuant] prevented stop substitution, and constraints against the non-default manner features of [h] favored preservation of the final stop.

Restrictions on place feature sequences were implicated in initial stop deletion, modeled by **Agree(C-Place)** and **Agree(Lingual)**. Deletion of an initial labial or coronal stop occurred in the presence of a final fricative as in *please* [is] due to a higher priority placed on preservation of [+continuant] than on preservation of place features, modeled in a high ranking of **Survived(+continuant)**. Deletion of an initial labial or coronal stop also occurred in the presence of a final velar as in *book* [oʊk] due to a dispreference for initial velars (reflected in **NotCo-occurring(Onset,Dorsal)**) that prevented [Dorsal] from spreading to initial position (although it was permitted word-initially when underlying). At the same time, labial and velar harmony were attested in coronal-final sequences as in *boat* [boʊp] and *coat* [koʊk], which do not require spreading [Dorsal] to initial position.

The primary motivation for variable deletion of initial fricatives, affricates and glides was not sequence constraints, but manner feature restrictions in initial position, attributed to the sonority-related constraints **Co-occurring(Onset→ -continuant)** and **Co-occurring(Onset→ +consonantal)**. For initial continuants, [h] substitution was frequently preferred over deletion since it fulfilled faithfulness constraints for manner features; however, the sequence constraint **NotTwice(+continuant)** played a role in preferring deletion in a sequence of [+continuant] consonants as in *shoes* [us]. Generally speaking, Grace's error patterns reflected a higher priority placed on faithfulness to manner features over place features. The learning process was modeled via the demotion of output constraints in combination with the promotion of faithfulness constraints, particularly **Survived(Place)**, whose promotion led to the acquisition of initial fricatives and glides.

Deriving Grace's initial consonant deletion patterns proved to be somewhat complicated, requiring specific rankings of multiple constraints. This might be seen as a disadvantage of the analysis if these patterns were common. However, considering that her particular patterns of initial stop deletion with concurrent harmony and later variable initial continuant deletion are somewhat unusual, the fact that these specific rankings are required is actually an advantage of the model, since we would not want to predict that these patterns could easily obtain when they are rarely attested. It is also important to note that the specific rankings proposed here also needed to make the correct predictions for Grace's onset cluster reduction patterns, examined in Chapter 6 below; otherwise I may have arrived at a simpler analysis.

In the following section, I explore how the constraints responsible for Grace's initial consonant deletion patterns can help us understand initial consonant deletion patterns attested across children. I also discuss the advantages of this constraint-based model over other accounts of initial consonant deletion.

5.3 Initial consonant deletion in phonological development

5.3.1 Initial consonant deletion patterns and elimination

As discussed in 5.1, the cases of initial consonant deletion reported in studies of early phonological development frequently initial fricatives or other [+continuant] consonants, as well as target sequences of different consonants. This is just as expected given the set of constraints involved in Grace's initial consonant deletion patterns. In her grammar, deletion of an initial consonant was motivated by two primary considerations: a problematic sequence of different place and manner features, or sonority preferences for vocal tract closure in onsets. While the specifics of her deletion, harmony, and substitution patterns are not replicated in other children, the constraints leading to these patterns can nevertheless account for trends in initial consonant deletion patterns across children.

Constraints limiting possible sequences of features are relevant in many cases of initial consonant deletion, given the numerous examples cited in 5.1 of initial consonants that are deleted when followed by a different consonant but retained in harmonic forms. Deletion of one of the consonants in a sequence is just one way of dealing with the speech planning challenges inherent in producing sequences of different place or manner features, but can be optimal in some scenarios, especially if **Survived(Place)** and **Survived(C-Root)** are not highly ranked. Segmental deletion can be preferable to an unfaithful substitute due to featural faithfulness constraints and/or constraints against production of non-default features.

While **Not(Coda)** prefers deletion of a coda consonant, deletion of the initial consonant can be preferred if other constraints are ranked higher. One possibility, depending on the particular sequence, is that faithfulness constraints may favor preservation of the non-default place or manner features of the second consonant rather than the initial consonant, e.g. preservation of /l/ in Finnish *kala* [ala] 'fish' due to **Survived(+lateral)**. Another possibility is a high ranking of **Priority(Last,C-Root)** or **Priority(Last,C-Place)**, which will favor preservation of the second consonant in the sequence due to the anticipatory nature of speech planning (although as it turns out, this constraint was not necessary to account for Grace's data). If the second segment in the sequence is a medial consonant rather than a coda, another reason to prefer initial consonant deletion is the avoidance of vowel hiatus. This may partly explain the apparently higher incidence of initial consonant deletion in the studies of Finnish and Italian acquisition reviewed above (Savinainen-Makkonen 2000 and Keren-Portnoy et al. 2009), languages in which codas are less frequent and children attempt many more disyllabic words. The presence of medial geminates is another factor in favoring initial consonant deletion in these languages, since the additional **Survived(C)** constraint applying to the long medial consonant will favor preservation of the geminate over the initial segment.

The other trend observed in reports of initial consonant deletion across children is that it often affects continuants. This is consistent with the onset sonority co-occurrence constraints used to motivate initial fricative and glide deletion in Grace's speech. **Co-occurring(Onset→ -continuant)** may prohibit initial fricatives (as well as glides) and **Co-occurring(Onset→ +consonantal**) can also prohibit initial glides.[169] Whether or not these constraints lead to deletion depends on the ranking of other constraints. Many children will never delete initial fricatives, opting instead for segmental substitution in all contexts due to a higher ranking of **Survived(C-Root)**, **Survived(Place)**, or possibly **Co-occurring(σ→Onset)**. A high priority placed on preservation of manner features may result in [h] substitution, while a higher priority placed on place feature preservation may result in fricative stopping. Many children find stops to be the optimal substitute for an initial fricative, since they differ only in [continuant]. Stopping is not similarly attested for initial glides since they share no manner features.[170]

An advantage of the present analysis is that it helps explain why children with initial consonant deletion typically progress from a deletion strategy to substitution, but not the reverse. Part of the reason is that substitution may result in a consonant or sequence that is problematic for other reasons, e.g. fricative stopping in *sock* [tak] creates a Coronal…Dorsal sequence, while harmony [gak] requires an initial velar. Initial consonant deletion may be the easiest way out in the face of numerous early production constraints. Once some of these output constraints (e.g. **NoSequence(Coronal…Dorsal**) have been demoted, substitution may become a viable strategy. Positing independent **Survived** constraints for each element of the underlying representation also helps explain the progression from early deletion to substitution. Independent rankings of **Survived(C-Root)**, **Survived(Place)**, or other **Survived(F)** constraints can favor initial consonant deletion in some contexts and substitution in others, but as these faithfulness constraints are promoted (or production constraints are demoted), we expect that

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[169] Initial nasal deletion was also attested in some children, which could similarly be explained by a high ranking of **Co-occurring(Onset→ +consonantal)**.

[170] Specifically, stop substitution of a glide would violate **Survived(-consonantal)**, **Identical(+continuant)**, and **Identical(+sonorant)**.

substitution will be preferred. The use of all-or-nothing IDENT[F] and MAX-IO constraints on the other hand, does not make this prediction. A child with an initial ranking of IDENT[F] >> MAX-IO prefers deletion to substitution since IDENT is vacuously satisfied by deletion, while a child with an initial ranking of MAX-IO >> IDENT[F]) prefers substitution to deletion. Since these constraints may be freely re-ranked, there is no predicted order in development for the preference for one strategy over the other, contrary to what is actually observed.

Another major advantage of this analysis is that the constraints that motivate initial consonant deletion are not idiosyncratic or child-specific. Constraints on sequences of features are firmly grounded in speech planning considerations and are responsible for a variety of processes. Consonant harmony, metathesis, and deletion all conspire to avoid problematic sequences; the ranking of various faithfulness constraints determines which process is optimal. Similarly, onset sonority constraints account for the range of processes that conspire to avoid initial fricatives, including stopping, deletion, and even metathesis, as in *fall* [af] and *zoo* [uz] reported for 'W' (Leonard and McGregor 1991). By contrast, the use of a more specific ALIGN(Fricative, Right) constraint (Velleman 1996) accurately describes the output, but lacks a principled motivation and loses the conspiracy effect captured in the use of onset sonority constraints.

The analysis of initial fricative deletion presented here is similar to that in Grijzenhout and Joppen-Hellwig (2002) in its appeal to a constraint preferring [-continuant] segments in initial position and a low ranking of the constraint mandating onsets. However, their assumption that the constraint against segmental deletion is low-ranked in child phonology leads them to posit the novel markedness constraints CONSONANT and VOWEL, mandating at least one consonant and one vowel in a word, in order to avoid rampant deletion.[171] The present analysis does not require these child-specific

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[171] Children's earliest words do sometimes consist of only one vowel, e.g. *nose* [o], *read* [i] (Menn 1971); or one consonant, e.g. *fish* [f], *shoe* [ʃ] (Matthei 1989). My son's earliest productions included words consisting of only a vowel (*Cheerios* [o]) and only a consonant (*shoes* [ʃ],

constraints. While initial consonant deletion requires a relatively low ranking of several constraints, including **Co-occurring(σ→Onset)**, **Not(Coda)**, **Survived(C-Root)** and **Survived(Place)**, preservation of a segment can be motivated by **Survived** constraints for non-default features, obviating the need for the special constraints CONSONANT and VOWEL. The fact that onset and coda deletion are mutually exclusive in the German data falls out from the fact that deletion occurs either to avoid a problematic sequence or a problematic onset, motivating only one consonant to delete. The current model additionally explains why initial consonant deletion is not reported as frequently as either consonant harmony or fricative stopping. The fact that low rankings are required for all of the above-mentioned constraints makes initial consonant deletion somewhat unlikely to arise.

When it does occur, initial consonant deletion is typically eliminated early in favor of less drastic repairs as children acquire additional feature sequences and become more faithful to the adult forms, modeled in the demotion of sequence constraints or promotion of the relevant faithfulness constraints. A likely contributing factor to the absence of initial consonant deletion in adult phonology is the fact that omission of initial consonants is highly disruptive to a child's intelligibility (Howell and Dean 1994).[172] The need to make themselves understood will typically motivate children to eliminate this process early in their development. The deletion of an entire segment is a drastic repair resulting in the loss of all featural information, and is typically a "last resort" repair when a child's limited production abilities makes substitution unviable. Children's increasing need for faithfulness and maturing speech coordination skills eliminate the need to delete the segment entirely, leading either to other types of repair such as fricative stopping, as in the case of Amahl (Smith 1973) or to accurate production of the segment, as in Grace's case.

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snack/Chex [$\mathrm{k^h}$]. Bernhardt and Stemberger (1998: 391) cite *shoe* [ʃ] and *cheese* [ts] as examples of syllabification of an initial consonant, but observe that this is "highly unusual."

[172] For this reason initial consonant deletion is a high priority for treatment in children with phonological disorders.

The lack of initial consonant deletion in adult phonology may also be attributable to some of the same factors that disfavor consonant harmony and long-distance metathesis of major place features in fully developed languages, discussed in 4.2.2. Many phonological alternations in mature languages have diachronic origins in the misperception of low-salience contrasts. Onset deletion is unlikely to arise in this manner, given the high salience of the consonant-vowel transitional cues in this prosodically prominent position. In addition, a language that does not permit initial consonants differing from a following consonant in place or manner features would be severely limited in terms of possible lexical contrasts.

This analysis also differs significantly from that of Dinnsen and Farris-Trimble (2008), who propose a set of prominence-assigning constraints to account for a variety processes in child speech that neutralize contrasts in initial position, including initial consonant deletion, initial fricative stopping (as in *vanilla* [bənɪjə] but *glove* [glʌv]), positional velar fronting (as in *cooking* [tʊkɪŋ]), and anticipatory harmony (as in *take* [kek], *yellow* [lɛlo], and *pin* [mɪn]).[173] Based on this evidence, they observe that "word-initial position behaves as if it were weak relative to final position" (Dinnsen and Farris-Trimble 2008: 284). This leads them to suggest that prominence must be assigned to final position in child phonology, shifting to initial position only later in phonological development. They therefore posit an initial ranking of the prominence assigning constraints FINALPROM >> INITIALPROM, later re-ranked to INITIALPROM >> FINALPROM, possibly due to "increases in the size of the lexicon and the need to differentiate words in more densely packed neighborhoods" (Dinnsen and Farris-Trimble 2008: 288). The stipulation that FINALPROM >> INITIALPROM is the initial default ranking, however, does little to explain why this might be the case. Furthermore, the hypothesis that final position is

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[173] Dinnsen and Farris-Trimble (2008) additionally claim that the voicing contrast for stops often is acquired first in final position while being neutralized in initial position (as voiceless unaspirated), contrasting this with mature languages, in which obstruent voicing contrasts are often neutralized word-finally. However, other sources report that the voicing contrast is acquired last in final position (Templin 1957, Ingram 1989), and final obstruent devoicing is reported in studies of acquisition (e.g.Velten 1943, Leopold 1947, Bernhardt and Stemberger 1998, and the present study). This apparent contradiction may be due to variability in the acquisition of aspiration associated with the English voicing contrast in initial stops.

prominent in early phonological development seems at odds with studies of early perception indicating that infants are sensitive to shared features in syllable onsets but not codas (Jusczyk, Goodman and Baumann 1999), and that children perceive consonant contrasts better in initial position than in second position, either in codas (Barton 1976; see also Swingley 2005 for Dutch[174]) or as the onset of a medial unstressed syllable (Vihman et al. 2004[175]).

The present analysis avoids the need for special prominence-assigning constraints with a child-specific ranking, relying instead on independently motivated constraints account for the various processes that neutralize contrasts in initial position. Neutralization of manner contrast for obstruents in initial position is expected due to onset sonority constraints associated with closed-open cycles of the vocal tract. The neutralization of place contrast in initial velar fronting is similarly attributable to feature preferences for onsets and rimes, since [Dorsal] is associated with the open vocal tract position of vowels. The neutralization of initial place and manner contrasts in harmony is a natural result of speech planning principles favoring anticipation of later features, especially non-default features. This is reflected in **NoSequence(Default…Non-default)** constraints as well as the **Priority(Last, X)** constraint (discussed at length in 4.1.2). Initial consonant deletion can also satisfy **Priority(Last)** by preserving the last segment of a problematic sequence, or occurs in response to the same onset sonority constraints that motivate initial fricative stopping. All of these processes can be understood in terms of the acquisition of sequences and initial manner features.

While the constraints that motivate initial consonant deletion in children do not cause deletion in adult phonology, their effects do not disappear. The role of **Agree** constraints (favoring featural agreement in sequences) and **Priority(Last)** (favoring preservation of an anticipated consonant) is evident in anticipatory consonant harmony

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[174] Specifically, Dutch 11-month-olds preferred correct pronunciations of familiar words over mispronunciations involving a single featural change in onsets, but not in codas.

[175] In English-acquiring 11-month-olds, changing the initial consonant of familiar words blocked word recognition, while change to the second consonant did not.

patterns attested in adult phonology, as discussed in 4.2.2. Onset sonority preferences are evident in fortition processes for onset consonants and in stop-fricative alternations in languages such as Spanish, where [b] occurs word-initially and [β] post-vocalically. **NotTwice** constraints underlie dispreferences for repetition of a feature in adult phonology. Examples of **NotTwice(Labial)** motivating the avoidance of a sequence of labials include casual pronunciations of *helpful* as [hɛɫp̪fɫ] or [hɛɫʔfɫ], as well as the common substitution of [j] for the rounded rhotic glide [ɹ] in *February* as *Fe*[bju]*ary* and the common mispronunciation of *library* as [laɪbɛɹi]. While positional velar fronting per se is not attested in adult language, the dispreference for initial dorsals leaves a trace in a lower frequency of initial velars and prohibitions on initial velar nasals in many languages (see 4.1.3 for discussion and references).

5.3.2 The acquisition of consonant sequences: from tier adjacency to root adjacency

In this chapter and the preceding chapter, we have observed the effects of constraints on sequences of features for consonant tier adjacency (i.e. with an intervening vowel), manifested in consonant harmony, long-distance metathesis, and initial consonant deletion. All of these processes are characteristic of early acquisition data and typically occur prior to the acquisition of onset clusters. Indeed, in Grace's case, all of these processes had been eliminated by age 1;11, when she began acquiring onset clusters. One way to view this progression is that consonant place feature sequences must be acquired first at the tier-adjacent level within a syllable before being acquired at the root-adjacent level. This can be understood intuitively from a speech planning perspective, in that production of the immediately adjacent Coronal…Labial sequence in the /sp/ onset of *spy* implies the ability to execute a non-local Coronal…Labial sequence within a syllable as in *soap*, since an onset is a subset of the syllable. The reverse is not true; i.e. production of the Coronal…Labial consonant sequence in *soap* does not imply acquisition of the immediately adjacent Coronal…Labial sequence in the /sp/ onset of *spy*, since the syllable is not a subset of the onset.

Some support for this view comes from an example of treatment for a child with a phonological delay who exhibited anticipatory labial harmony in Coronal…Labial sequences and a constraint against onset clusters (Stemberger and Bernhardt 1997). A decision was made to address the two problems simultaneously by targeting the tautosyllabic clusters /sp/ and /sm/. After about six weeks of treatment, the child produced some /sp/ and /sm/ clusters and also produced his first noncontiguous spontaneous Coronal…Labial sequence in the word *zipper* [lɪpʊ] (albeit with overgeneralized [l]). This result is expected if the acquisition of root-adjacent feature sequences implies the acquisition of tier-adjacent sequences.

This order of acquisition may also provide an explanation for the fact that children consistently acquire codas prior to clusters, i.e. CVC < CCV (Fikkert 1994, Lleó and Prinz 1996, Levelt, Schiller, and Levelt 2000, Meade 2004), as well as a strong cross-linguistic implicational tendency for languages with clusters to also have codas (Kaye and Lowenstamm 1981, Baertsch and Davis 2003). This is not predicted by the syllable structure constraints of classic OT given in (163).

(163) Syllable structure constraints in OT (Prince and Smolensky 2004/1993)
ONSET: A syllable must have an onset.
NOCODA: A syllable must not have a coda.
*COMPLEXONSET: A syllable must not have a complex onset.

These syllable structure constraints correctly predict the cross-linguistic implication that a language with onsetless syllables (V or VC syllables) will also allow syllables with onsets, and a language allowing codas (CVC or VC syllables) will also allow open syllables (implications that are also true in acquisition). That is, a CV syllable is the least "marked" syllable and is therefore expected in every language as well as in the earliest stage of acquisition. However, these constraints fail to predict that the presence of onset clusters (CCV syllables) in a language or child implies the presence of codas (CVC syllables. Boersma and Levelt (2000) attribute the CVC < CCV order of acquisition in Dutch to the greater frequency of CVC syllables in the linguistic input given to the child. While frequency is undoubtedly an important factor in acquisition, the categorical absence of other orders of acquisition is nevertheless surprising. Children (and languages) should show variation corresponding to different rankings of NOCODA and

*COMPLEXONSET with respect to faithfulness constraints, producing some grammars where CCV is acquired before CVC (or languages in which CCV occurs without CVC), but they do not.

Although not claimed explicitly by Bernhardt and Stemberger (1998), their model actually predicts the acquisition of tier-adjacent sequences prior to root-adjacent sequences within a syllable. While any sequence of consonants within a syllable is adjacent at the consonant tier level, only immediately adjacent consonants are adjacent at the root level. In other words, root adjacency of consonant features within a syllable entails tier adjacency, but not vice versa. This is true because the features of the onset cluster in a [C_1C_2V] syllable are adjacent at both the root and tier levels, while the consonant features in a [C_1VC_2] syllable are only adjacent on the consonant tier, as shown in (164).

(164) Consonant place feature adjacency levels

a) Within an onset cluster (CCV): Root adjacency and tier adjacency

[C_1 C_2 V]
| |
C-Place C-Place

b) Across a vowel (CVC): Tier adjacency only

[C_1 V C_2]
| |
C-Place C-Place

Since onset clusters contain sequences of consonant place and manner features, and the onset is a substructure of a syllable, these sequences must be possible within a syllable in order to be produced within an onset. In the constraint set employed here, this is reflected in the fact that an /sp/ onset violates both **NoSequence^{Root}(Coronal…Labial)** and **NoSequence^{Tier}(Coronal…Labial)**, while the same sequence in *soap* violates only **NoSequence^{Tier}(Coronal…Labial)** (where the domain of application is the syllable).

As a result, acquisition of root-adjacent consonant sequences should imply acquisition of tier-adjacent consonant sequences, since acquisition of root-adjacent consonant sequences requires demotion of both **NoSequence$^{\mathbf{Root}}$** and **NoSequence$^{\mathbf{Tier}}$** constraints.

This progression from tier adjacency to root adjacency for the acquisition of consonant feature sequences is evident in Grace's acquisition of onset clusters. Having eliminated initial consonant deletion, non-local metathesis, and consonant harmony, she is ready to move on to the acquisition of feature sequences for immediately adjacent consonants. With this in mind, I proceed to a detailed examination of Grace's onset cluster acquisition.

6 Onset cluster reduction patterns

"The acquisition of consonant clusters is gradual…it is not an all-or-nothing process."
--McLeod, van Doorn, and Reed (2001: 1146)

6.1 Onset cluster reduction in acquisition

The acquisition of onset clusters poses a particular challenge. Cluster reduction, the most common adaptation of clusters in younger children, is typically one of the last phonological error patterns to be eliminated in acquisition (Bankson and Bernthal 2004, Grunwell 1987). While other processes such as consonant harmony, coda deletion, fricative stopping, and velar fronting are common in acquisition, cluster reduction is the only process universally attested in children acquiring a language with onset clusters. Later errors in onset cluster production include substitution of one or more elements (e.g. *black* [bwæk], *slide* [fwaɪd]) or more rarely, epenthesis (e.g. *black* [bəlæk]). The focus of the present study is cluster reduction, which may occur via deletion of the initial consonant, e.g. *snow* [noʊ]; deletion of the second consonant, e.g. *snow* [soʊ]; or coalescence, where features from more than one segment surface in a single consonant (e.g. *tree* [pi] or *swing* [fɪŋ]).

It has been suggested that cluster reduction tends to preserve either the least sonorous consonant (Gnanadesikan 1995/2004, Jongstra 2003, Ohala 1999, Bernhardt and Stemberger 1998, Smit 1993, Chin and Dinnsen 1992, Fikkert 1994) or the least marked segment, where markedness is based on the normal order of acquisition for singleton consonants (Smit 1993). Given the common sonority scale in (165) (e.g. Selkirk 1984, Blevins 1995), both of these considerations point to the stop being preserved in a cluster that contains a stop, while they conflict in their predictions for fricative+nasal clusters, where sonority would favor deletion of the nasal but markedness would favor deletion of the fricative. Typical examples of this type of cluster reduction in English acquisition are given in (166).[176]

(165) Sonority scale for consonants, least sonorous to most sonorous

Stops < Fricatives < Nasals < Liquids < Glides

(166) Cluster reduction preserving least sonorant segment (Locke 1983)

a) Obstruent + liquid/glide: obstruent preserved

queen [kin] *blue* [bu] *swing* [sɪŋ] *fly* [fai]

b) Fricative + stop: stop preserved

spoon [pun] *stop* [tap]

However, considerable variation occurs across children for /s/-initial clusters, especially /s/+sonorant (Ohala 1999, Jongstra 2003, Pater and Barlow 2003, Grunwell 1982). Smit (1993) finds that with the exception of /sl/[177], /s/-initial clusters more often reduce to the second element (i.e. nasal, stop, or [w]), though reduction to the fricative is also reported. For /s/+nasal clusters, a nonsense word learning experiment found that approximately equal percentages of children reduced to the fricative and the nasal (Ohala 1999). Some variation is also reported for /s/+stop clusters, which may reduce to the fricative rather than the stop as in *stick* [sɪk] (e.g. Smith 1973, Ringo 1985 and references therein).[178] In the Ohala study, 14% of children retained the fricative in /s/+stop clusters. The examples in (167) illustrate the variation attested in reduction of /s/-initial clusters.

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[176] Locke (1983) notes that common cluster reduction patterns hold across different languages; however, a comprehensive cross-linguistic survey of cluster reduction is beyond the scope of this paper. As a result, discussion is generally limited to English acquisition.

[177] Smit (1993) finds that /Cl/ clusters typically reduce to the obstruent since /l/ is acquired later. Ohala (1999) also found that a large majority of fricative+/l/ clusters reduced to the fricative.

[178] I also personally observed this cluster reduction pattern in "Tyler" and "Emma," two children I interacted with on a regular basis as a caregiver.

(167) Variation (across children) in /s/-initial cluster reduction

a) /s/ + nasal clusters

snow [noʊ] or [soʊ] (Pater and Barlow 2003)

b) /s/+glide clusters

swing [sɪŋ] (Locke 1983) *swing* [wɪŋ] (Grunwell 1982)

c) /s/+stop clusters

stop [tap] (Locke 1983) *stool* [suw] (Ringo 1985)

Interestingly, place features may affect reduction patterns for /s/+nasal and /s/+stop clusters. In a study of Dutch acquisition, the non-coronal consonant was more likely to be preserved. That is, 77% deleted the nasal in /sn/, but only 42% in /sm/; similarly, 80% preserved the stop in /st/ onsets, but 92% preserved the stop in /sk/ onsets (Jongstra 2003). Amahl (Smith 1973) showed similar variation in his /s/+stop reduction pattern for coronal and non-coronal stop clusters beginning at age 3;0 (after the acquisition of initial fricatives) as illustrated in (168).

(168) Variation in /s/+stop cluster reduction by place feature (Smith 1973)

a) /s/+coronal stop clusters

stamp [sæmp] *start* [saːt] *stay* [sei]

still [sil] *stuck* [sʌk]

b) /s/+non-coronal stop clusters

spice [pais] *sponge* [pʌnz] *spinach* [piniz]

spiders [paɪdəz] *scales* [keilz] *school* [kuːl]

Cluster reduction does not always involve the clear deletion of one segment and preservation of the other, however, given instances of coalescence in which features from more than one segment survive. For example, some children reduce /s/+sonorant clusters to a voiceless sonorant. This is reported for /s/+nasal clusters, e.g. *sneeze* [n̥id] (Smith 1973, Greenlee 1973) as well as laterals, e.g. *slug* [ɬʌg] (Smith 1973), where [+nasal] or [+lateral] is preserved along with the [+s.g.] feature of the fricative. Another example occasionally cited in English acquisition is reduction of a /tɹ/ onset to [f], rather memorably exemplified in productions of *truck* as [fʌk] (Greenlee 1973, Ringo

1985), where [+continuant] and [Labial] from /ɹ/ appear with the stop's [-sonorant] feature.[179]

Certain cluster types seem particularly susceptible to coalescence in English acquisition. Ringo (1985) observes that coalescence frequently affects /sw/ onsets, based on reports from multiple sources (e.g. Velten 1943, Leopold 1947, Smith 1973). Smit (1993) makes the same observation, characterizing coalescence as occurring rarely or occasionally for most cluster types but more frequently for target /sw/ clusters. Coalescence resulting in a labial fricative is the most common coalescence pattern attested and is reported for various /s/+labial clusters, as illustrated in (169).[180]

(169) Examples of coalescence involving fricatives and labials

sweet [fiːt]			(Smith 1973)
swing [ɸɪŋ]	*sweetheart* [ɸithaːt]		(Leopold 1947: 164)
spell [fɛw]	*small* [faw]		(Chapin 1983)
spell [fɛw]	*spring* [fɪŋ]	*smell* [fɛw]	(Ringo 1985)
spider [faɪdə]	("Tyler," personal observation)		

The acquisition of onset clusters (and concomitant elimination of cluster reduction) proceeds in a gradual manner, rather than all at once. A study of 16 English-acquiring two-year-olds found that all but two produced some onset clusters, but none had acquired all of the onset clusters of English (McLeod et al. 2001). Certain cluster types tend to be acquired later than others. Data collected in the Iowa-Nebraska normative study for English indicates that stop-initial clusters, especially /tw/ and /kw/, are generally acquired earlier than clusters containing fricatives (Smit 1993). In 16 children studied by McLeod et al. (2001), acquisition of a fricative-initial cluster implied the acquisition of a stop-initial cluster, but not vice versa. Similar findings are reported for

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[179] A cousin of mine also had this early pronunciation of *truck* (which family members never let him live down).

[180] Smit (1993) found that labial fricatives often appear in cluster substitutions as well, with [fw] substituting for numerous obstruent+approximant target clusters.

Dutch acquisition, where most children acquire stop-liquid clusters before /s/ clusters (Fikkert 1994: 109).

Ringo (1985) and studies cited therein found that among /s/ clusters, the first cluster acquired was typically an /s/+approximant cluster. Order of acquisition of other /s/ clusters varies. A study of 110 English-acquiring children with phonological delays found that /sl/ was the latest /s/ cluster acquired. However, /sl/ was my son Benjamin's first /s/ cluster, and other studies report this order of acquisition as well. Amahl (Smith 1973) acquired /sl/ at 3;2; /sn/, /sw/, /sm/, and /sp, sk/ at 3;3 (in that order), and finally /st/ at 3;4. Another longitudinal study subject (Allerton 1976) acquired /sl/ at 4;3, /sm/ at 4;9 and /sn/ at 5;3, but had not acquired other /s/ clusters by the end of the study, producing /sp/ as [f] and /st, sk/ as long [s]. Children may also go through different stages in the acquisition of a given cluster type. Amahl, for example, deleted the fricative in /st/ clusters at 2;4 as in *stop* [d̥ɔp], but preserved the fricative after acquiring fricatives at 2;11, as in *stop* [sap] (Smith 1973).

An adequate model of onset cluster acquisition should account for trends across children while allowing for the variety of cluster reduction patterns attested, especially for /s/ clusters. Since sonority considerations do not account for all /s/ cluster reduction patterns, recent analyses have relied on special treatment of /s/ as a syllable adjunct (Gierut 1999, Barlow 2001, Jongstra 2003, Goad and Rose 2002) or its perception by children as an unstressed degenerate syllable (Kwon and Stanford 2006). It would seem preferable, however, to avoid these assumptions if other factors can offer a principled explanation for the variety of reduction patterns involving /s / clusters.

While it is useful to consider trends across children, it is difficult to attribute cluster reduction patterns to specific factors without a complete picture of a child's consonant inventory and the contextual constraints for production of each consonant. There are still relatively few studies that present complete longitudinal data on cluster acquisition permitting this type of analysis (exceptions being Smith 1973 for Amahl; Ringo 1985 for

Megan; and Compton and Streeter 1977 for Trevor[181]). In 6.2.1, I present longitudinal data on Grace's onset cluster development illustrating the gradual acquisition of onset clusters and how cluster reduction patterns can vary by cluster type and change over time, to include deletion of the first segment, deletion of the second segment, and coalescence. In 6.2.2, I argue that these patterns result from the interaction of faithfulness constraints with constraints governing sequences of features and onset sonority preferences. In this way, the same basic constraints that motivate Grace's harmony, metathesis, and initial consonant deletion patterns are also responsible for her onset cluster reduction patterns, without requiring any additional constraints or special treatment of initial /s/ in the syllable structure.

6.2 Case study in onset cluster acquisition: Grace

6.2.1 Data

As is typical, Grace's early words include no consonant clusters. Target onset clusters are reduced to a single segment by deletion of one of the consonants (or in the case of a three-member onset, deletion of two segments).[182] In (170)a-c, the stop is consistently preserved, corresponding to the least sonorous segment; however, in /s/+nasal clusters (represented as /sN/), the nasal is preserved, as in (170)d.

(170) All clusters reduced to oral or nasal stops prior to 1;10

a) Stop+approximant clusters:
cracker [kækə] *blow* [boʊ] *brush* [bʌs] *broccoli* [baki]
plate [peɪt] *glasses* [gæs] *clock* [kak]

b) /s/+stop clusters:
spider [paɪ] *spoon* [pun] *stuck* [tʌk] *stick* [tɪk] *straw* [ta]

c) /sN/ clusters (1;7-1;9):
snake [neɪk] *snack* [næk] *snap* [næp]

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[181] See Tessier (2007) for an analysis of Trevor's onset cluster acquisition.

[182] A few onset clusters are deleted entirely prior to 1;7, as in *please* [is] and *snake* [eɪk]. This is discussed in the context of Grace's initial consonant deletion patterns in 5.2.2.

At 1;10, subsequent to her acquisition of word-initial fricatives at 1;9, a change occurs in in her cluster reduction patterns. Although most cluster types continue to be reduced according to the patterns in (170), the nasal is now deleted in /s/+nasal clusters, preserving a fricative that shares the stop's place of articulation. That is, in the case of /sm/ clusters, coalescence occurs, resulting in a bilabial fricative preserving the manner features of /s/ but the labial place feature of /m/, as shown in (171).[183]

(171) Cluster reduction patterns at 1;10

a) Stop-initial and /s/+stop clusters reduced to stop (unchanged):

blood [bʌt]   *please* [pis]   *crash* [kæʃ]   *Grace* [geɪs]

stuck [tʌk]   *stick* [tɪk]   *stop* [tap]

b) /sN/ clusters reduced to fricative (with labial coalescence):

snack [sæk]   *snap* [sæp]   *snake* [seɪk]

smell [ɸɛʊ]   *smooth* [ɸuβ]

At age 1;11 (shortly after acquiring the labio-velar glide [w]), Grace uses [w] to acquire her first complex onsets, consisting of obstruent+glide.[184] This cluster type now substitutes for all target obstruent+approximant clusters as shown in (172), consistent with across-the-board liquid gliding at this time.

(172) First complex onsets at 1;11: obstruent+glide

a) Target stop+approximant clusters:

Grace [ɡweɪs]   *crash* [kwæʃ]   *please* [pwis]   *plate* [pweɪt]

b) Reduction of three-member clusters to stop+glide:

square [kweə]   *squeak* [kwik]

c) Target fricative+approximant clusters:

sleep [swip]   *flag* [ɸweg]   *flower* [ɸwawʊ]

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[183] Grace substitutes bilabial fricatives for labiodental fricatives across the board until age 2;10, when labiodental fricatives are finally acquired.

[184] Note that there are no obstruent+/j/ clusters in American English (e.g. *[tj], *[sj]). The apparent exception to this is limited to /Cju/ sequences where C is a labial or velar (as in *few*, *cute*, *puce*, *beauty*) and can be interpreted as the diphthong [ju].

However, other /s/-initial clusters continue to undergo reduction according to the patterns cited above, as in persistent productions of *snack* [sæk] and *smell* [ɸɛʊ] for /sN/ clusters, and the new vocabulary words *spill* [pɪʊ] and *spicy* [paɪsi] for /s/+stop clusters.

The next cluster type acquired is /s/+stop clusters, acquired for all places of articulation at age 2;4. This leads almost immediately to production of three-member clusters, i.e. combinations of the sequences she has already acquired (/s/+stop and stop+glide). The reduction pattern for /sN/ clusters remains unchanged.

(173) Acquisition of /s/+stop clusters at 2;4

a) Two-member clusters: *stick* [stɪk] *scared* [skɛʊd]
b) Three-member clusters: *stripe* [stwaɪp]

The last cluster type acquired is /sN/ clusters, which she finally masters at age 2;9, as evidenced by accurate productions of the clusters in (173).

(174) Acquisition of /sN/ clusters at 2;9

snack [snæk] *snap* [snæp] *smell* [smɛʊ]

This eliminates all cluster reduction in Grace's phonology. Further advances in her cluster acquisition are limited to the acquisition of accurate /ɹ/ and /l/ in clusters, which is simply correlated with her acquisition of /ɹ/ and /l/ respectively.

6.2.2 Analysis

In the analysis of Grace's cluster acquisition, some constraints motivate the reduction of onset clusters, while other constraints are relevant in determining the features of the segment that survives. Beginning with the former, the most commonly cited constraint in OT to motivate cluster reduction is a general constraint against complex onsets that prohibits any consonant cluster within an onset. However, given the gradual acquisition of different cluster types, this constraint is clearly insufficient to account for all cases of cluster reduction. Following Bernhardt and Stemberger (1998), I conclude that the gradual acquisition of clusters results from difficulties in planning and executing specific consonant feature sequences. Constraints on specific sequences of features prevent some clusters from being realized while other clusters are possible.

To review, in Bernhardt and Stemberger (1998), consonant feature sequences are governed by two types of constraints on sequences of features (introduced in 2.2.3). **NoSequence** constraints prohibit a specific ordering of features, often affecting a Default…Non-default sequence such as **NoSequence(Coronal…Labial)** or **NoSequence(-nasal…+nasal)** (see discussion in 4.1.2). The other type of sequence constraint, **NotTwice**, prohibits a sequence of identical features or feature nodes, e.g. **NotTwice(Labial)** or **NotTwice(+continuant)**. As discussed in 2.2.3, I argue that there are two variants of this constraint with independent functional groundings. One variant of **NotTwice** prohibits two adjacent tokens of a feature node such as [Place] or [Dorsal] and can therefore be satisfied by feature sharing, i.e. assimilation (in violation of **SinglyLinked** for that feature). I argue that this constraint, which disprefers a sequence of different feature values, is functionally grounded in speech planning considerations. Planning and executing a sequence of different features requires more cognitive resources than a sequence of the same features. I prefer to use the constraint name **Agree(Feature)** for this purpose. The constraint is not limited to prohibiting a sequence of feature nodes such as [Place] with differing dependent features, but can apply to any feature; e.g. **Agree(continuant)** prefers a sequence sharing the same value of [continuant].

By contrast, **NotTwice(+continuant)** prohibits the repetition of this feature in a sequence, effectively *preferring* a sequence of segments differing in [continuant]. This constraint seems to contradict the **Agree** constraint; however, I argue that it has a different functional grounding and application. **NotTwice** as applied to aperture manner features is functionally grounded in sonority cycles, i.e. perpetuation of the open-closed cycles of the vocal tract that emerge in babbling and enforce syllable peaks and margins. For this constraint, feature sharing does not avoid a violation; rather, the constraint is violated any time the same aperture feature appears in adjacent segments. For example, **NotTwice(-continuant)** prohibits stop+stop onset clusters such as /pn/, active in adult English. The definitions of these constraints on sequences of features are repeated in (175).

(175) **NoSequence(A…B)**: Given two adjacent segments, if A and B are different values of a feature, A cannot be in the first segment if B is in the second; e.g. **NoSequence(Labial…Dorsal)**.

Agree(F): A sequence of segments differing in the feature F is prohibited, e.g. **Agree(Place)**, **Agree(voice)**.

NotTwice(F): A feature F may not appear twice in a sequence of segments, e.g. **NotTwice(-sonorant)**, **NotTwice(+continuant)**.

While sequence constraints such as **NoSequence** and **NotTwice** will be used to explain order of acquisition for Grace's clusters, they do not determine which segment is preserved in cluster reduction. Should the first or second segment be preserved? Should the segment of lowest sonority be preserved? Should place or manner features be preserved from both underlying segments? The answers to these questions depend on the ranking of other constraints. Onset sonority preferences can play a role, formalized in the co-occurrence constraints **Co-occurring(Onset→ -continuant)**, **Co-occurring(Onset→ -sonorant)**, and **Co-occurring(Onset→ +consonantal)** (introduced in 2.2.4), which favor features in onsets associated with a closed vocal tract. Faithfulness constraints also play a role in determining the segment or features that are preserved. **Contiguity** favors deletion of an initial segment as in *snow* [now], so as not to disrupt the contiguity of segments in the underlying form, while **Survived(F)** (for non-default features specified in the UR) and **Identical(F)** (for predictable non-default features) both favor preservation of non-default features. The role of these constraints in each stage of Grace's cluster acquisition is explored below.

In the initial stage of Grace's cluster acquisition, no complex onsets are permitted, which can be attributed to an undominated **NotComplex(Onset)** constraint. Her pattern of cluster reduction in this initial stage is repeated in (176).

(176) All clusters reduced to oral or nasal stops (age 1;3-1;9)

a)	Stop+approximant clusters:	*cracker* [kækə]	*glasses* [gæs]
b)	/s/+stop clusters:	*stop* [tap]	*spoon* [pun]
c)	/sN/ clusters:	*snack* [næk]	*snap* [næp]

Grace's cluster reduction pattern does not appear to be consistently governed by sonority, since the least sonorous segment is preserved in stop+liquid and /s/+stop clusters, but not in /sN/ clusters. Nor is it consistently governed by **Contiguity**; since deletion of initial /s/ in /s/+stop and /sN/ clusters respects this constraint, but deletion of the second consonant in stop+liquid clusters does not. Smit (1993) suggests that onset clusters may be reduced to the less marked segment, where markedness is determined by the typical order of acquisition for singleton consonants. This appears to be the most relevant consideration in Grace's early cluster reduction, since she produces no /l/ and no word-initial glides (including /ɹ/) due to highly ranked **Not(+lateral)** and **Co-occurring(Onset→ +consonantal)** (established in 5.2.3). The fact that she had not yet acquired initial approximants provides a straightforward account for deletion of the approximant in stop+approximant clusters.

Preservation of the least marked segment (based on order of acquisition) also explains why Grace consistently deletes the /s/ in initial /s/ clusters at this age. Fricatives are typically acquired later than stops, especially in word-initial position (Menn 1971, Bernhardt and Stemberger 1998, Brulard and Carr 2003, Fikkert 1994, inter alia). This often results in fricative stopping, either in all contexts or exclusively in initial position (Bernhardt and Stemberger 1998, Locke 1983, Fikkert 1994), although it can also lead to initial fricative deletion, as discussed in 5.2.3. Since Grace produces no word-initial fricatives until 1;9, deletion of the fricative in her /s/ clusters is expected.

As discussed in 5.2.3, the ranking of **Co-occurring(Onset→ -continuant)** above **Survived(+continuant), Survived(+s.g.)**,[185] and **Survived(Place)** was responsible for

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[185] In order to account for Grace's substitution patterns for initial fricatives and glides, it was necessary to assume that voiceless fricatives were specified for both [+continuant] and [+s.g.].

Grace's early patterns of initial fricative deletion and [h] substitution. One may object that initial [h] in Grace's speech seems inconsistent with the requirement that onsets be [-continuant]. To resolve this apparent contradiction, I suggested that onset sonority co-occurrence constraints apply only when there is a constriction of the articulators, preferring that this constriction be as closed as possible. Since /h/ involves no constriction of the vocal tract, but rather a [+s.g.] feature imposed on the features of the following vowel, the co-occurrence constraint does not apply to [h], which freely appears in onsets while fricatives are banned.[186]

This leads to the constraint rankings for cluster reduction patterns in Grace's initial stage of cluster acquisition. In fact, a number of different constraint rankings could be proposed to derive her patterns. However, rankings must be consistent with the rankings of the same constraints in the analysis of initial fricative and glide deletion patterns in 5.2.3. In the analysis to follow, therefore, I use some constraint rankings justified by previously analyzed data. Importantly, **Identical** constraints for predictable non-default features (such as [+sonorant] for nasals) are not relevant in determining which segment survives in cluster reduction. Since they are only relevant in evaluating a substitute for a given segment, they cannot motivate the survival of a feature when one of the segments is deleted. This distinction will be crucial in the later derivation of cluster reduction to the fricative in /sN/ clusters.

Prior to 1;9, the preservation of the oral or nasal stop in /s/-initial clusters can be straightforwardly explained by undominated **Co-occurring(Onset→ -continuant)**, which prohibited fricatives in onsets. Recall that consonant deletion violates both **Survived(C-Root)** and **Survived(C-Place)**, as well as **Survived(F)** for any non-default features specified for the segment, and therefore all instances of cluster reduction will violate these constraints. Since [h] was sometimes an optimal substitute for initial fricatives, I consider this candidate as well. Although [h] satisfies onset sonority and

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[186] In order to formally capture this generalization, onset co-occurrence constraints were redefined to apply only to segments with an underlying Place node, thus excluding glottals (see 5.2.3 for further discussion).

Survived constraints, it violates **Contiguity**.[187] The additional lower-ranked violations incurred by [h] substitution favor reduction to [t].

(177) /s/ deletion in /s/+stop clusters

Input: *stop* /stap/	[stap]	[sap]	[hap]	[tap]
NotComplex(Onset)	*!			
Co-occurring(Onset→ -continuant)	*	*!		
Survived(+continuant)				*
Contiguity		*	*	
Survived(+s.g)				*
Survived(C-Root)		*	*	*
Survived(Place)		*	**	*
Not(-consonantal)/Not(+sonorant)			*!*	

(178) /s/ deletion in /sN/ clusters[188]

Input: *snap* /snæp/	[snæp]	[sæp]	[næp]
NotComplex(Onset)	*!		
Co-occurring(Onset→ -continuant)	*	*!	
Survived(+continuant)			*
Contiguity		*	
Survived(+nasal)		*	
Survived(+s.g)			*
Survived(C-Root)/Survived(Place)		**	**

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[187] As defined previously in (43), **Contiguity** requires that elements contiguous in the UR also be contiguous on the surface and is therefore violated by [h] substitution for underlying /s/.

[188] I do not consider [h] substitution in this constraint table since I have already shown how it is ruled out for a similar cluster.

In the case of stop+approximant clusters, however, **Contiguity** is not sufficient to select the second member of the cluster. Using the constraint rankings established in 5.2.3 for age 1;7, the initial stop is preferred due to sonority preferences as well as constraints against the non-default features of the glide.

(179) Stop preservation in stop+approximant clusters

Input: *cracker* /kɹækəɹ/	[kwækə]	[wækə]	[kækə]
NotComplex(Onset)	*!		
Co-occurring(Onset→ -continuant)		*	
Co-occurring(Onset→+consonantal)		*	
Survived(-consonantal)			*
Contiguity			*
Not(-consonantal)/Not(+sonorant)		**!	

The promotion of **Survived(-consonantal)** proposed to account for initial /h/ preservation in *house* at age 1;8 is a potential problem for this analysis, since cluster reduction to [h] as in [hækə] would fulfill this constraint, yet this pronunciation was not attested. However, since faithfulness constraints can have lower rankings in weak prosodic positions (Beckman 1998, Bernhardt and Stemberger 1998: 223-227), including the second member of an onset, I suggest that **Survived(-consonantal)** was only promoted for initial onsets.[189] Since I have already shown how [h] substitution is ruled out for cluster reduction in (177), I do not consider [h] substitution for cluster reduction in the remainder of the analysis.

At age 1;10, Grace's cluster reduction pattern changes to preservation of a fricative for /sN/ clusters only as in *snack* [sæk] and *snap* [sæp], with coalescence appearing for /sm/ clusters as in *smell* [ɸɛʊ] and *smooth* [ɸuβ]. This change follows the acquisition of

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[189] This makes sense from a phonetic perspective, since a glide in initial position has a stronger gesture and greater duration than a glide occurring as the second member of an onset cluster.

initial fricatives at 1;9, but not immediately, since *snack* is still produced as [næk] towards the end of the month in which initial fricatives are acquired. In the analysis in 5.2.3, initial fricatives became possible as **Co-occurring(Onset→ -continuant)** was demoted and **Survived(Place)** was promoted to the same stratum as **Survived(+continuant)**. As seen in (180), this ranking continues to select fricative deletion as optimal.

(180) /s/ deletion in /sN/ clusters after acquisition of initial fricatives

Input: *snap* /snæp/	[snæp]	[sæp]	[næp]
NotComplex(Onset)	*!		
Co-occurring(Onset→ -continuant)	*	*	
Survived(+continuant)			*
Survived(Place)		*	*
Contiguity		*!	
Survived(+nasal)		*	
Survived(+s.g)			*
Survived(C-Root)		**	**

At 1;10, however, the fricative is preferred in /sN/ cluster reduction. I suspect this is the result of the promotion of **Survived(+s.g.)**, motivated by the need to fully acquire aspiration on initial voiceless stops.[190] The choice of which segment to preserve then falls to lower ranked **Co-occurring(Onset→ -sonorant)** as shown in (181), where onset sonority preferences lead to preservation of the fricative.

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[190] Although I do not address the acquisition of aspiration in detail, the relevant constraint in prohibiting stop aspiration would be **NotCo-occurring(-continuant,+s.g.)**, since she produced [+s.g.] in [h] and [s]. This constraint (along with **NotCo-occurring(+nasal,+s.g.)**) would also rule out a voiceless nasal, attested in some children's /sN/ cluster reduction (e.g. Smith 1973).

(181) Preservation of fricative in /sN/ clusters at 1;10

Input: *snack* /snæk/	[sæk]	[næk]
Co-occurring(Onset→ -continuant)	*	
Survived(+continuant)		*
Contiguity	*	
Survived(+s.g)		*
Survived(+nasal)	*	
Not(+sonorant)		*
Not(+continuant)/Not(+s.g.)	**	
Not(+nasal)/Not(+voice)		**
Co-occurring(Onset→ -sonorant)		*!

One might wonder whether **Co-occurring(Onset→ -sonorant)** should be ranked higher to facilitate preservation of the less sonorous fricative. In fact, it cannot be ranked higher because singleton nasal onsets appeared in Grace's earliest words despite the violation of this constraint. As shown in (182), nasal onsets are viable because **Survived(C-Root)** prevents deletion and **Identical(+sonorant)** prevents oral stop substitution.

(182) Preservation of singleton nasal onsets

Input: *no* /noʊ/	[noʊ]	[doʊ]	[oʊ]
Identical(+sonorant)		*!	
Survived(+nasal)		*	*
Not(+sonorant)	*		
Survived(C-Root)			*!
Not(+nasal)/Not(+voice)	*	*	
Co-occurring(Onset→ -sonorant)		*	

This example further supports the distinction between **Survived(F)** and **Identical(F)** discussed in 2.2.5 and 5.2.3. Crucially, faithfulness of the underlying nasal to the predictable non-default feature [+sonorant] must be attributed to **Identical(+sonorant)**. Unlike **Survived(F)**, which favors preservation of a feature in the output, **Identical(F)** evaluates a substitute correspondent segment, and is therefore irrelevant in determining what is preserved in cluster reduction. **Identical(+sonorant)** can therefore help preserve singleton nasal onsets without mandating nasal preservation in /sN/ cluster reduction.

Returning to the reduction pattern for /sN/ clusters, the constraint rankings already established also predicts coalescence for /sm/ onsets only, where a bilabial fricative surfaces due to **Survived(Labial)**. Since this involves delinking [Labial] from its underlying segment, **Survived(Link)** must be ranked in the lowest stratum.

(183) Coalescence in /sm/ clusters

Input: *smell* /smɛl/	[sɛʊ]	[mɛʊ]	[ɸɛʊ]
Co-occurring(Onset→ -continuant)	*		*
Survived(+continuant)		*	
Contiguity	*		*
Survived(Labial)	*!		
Survived(+s.g)		*	
Survived(+nasal)	*		*
Not(+sonorant)		*	
Not(+continuant)/Not(+s.g.)	**		**
Not(+nasal)/Not(+voice)		**	
Not(Labial)		*	*
Co-occurring(Onset→ -sonorant)		*!	
Survived(Link)			*

At the same time, stop preservation in /s/+oral stop clusters remains unchanged, though the decision now falls to lower ranked **Not(+continuant)**.

(184) /s/ deletion in /s/+stop clusters

Input: *stop* /stap/	[sap]	[tap]
Co-occurring(Onset→ -continuant)	*	
Survived(+continuant)		*
Contiguity	*	
Survived(+s.g)		*
Not(+continuant)	*!	

By this time, initial glides have been acquired, which was attributed in 5.2.3 to the promotion of **Survived(Place)** and demotion of **NotCo-occurring(Dorsal,Coronal)**, which are irrelevant for cluster reduction patterns. Indeed, stop preservation in stop+approximant clusters remains preferable to the glide, as shown in (185) for *Grace*, produced at 1;10. I consider only substitution of the palatal glide [j], since labio-velar glides were not acquired until 1;11 (due to **NotCo-occurring(Dorsal,Labial))** and /ɹ/ was not acquired during the period of this study.

(185) Stop preservation in stop+approximant clusters

Input: *Grace* /gɹeɪs/	[gweɪs]	[jeɪs]	[geɪs]
NotComplex(Onset)	*!		
Co-occurring(Onset→+consonantal)		*	
Survived(-consonantal)			*
Co-occurring(Onset→ -continuant)		*	
Survived(Place)		*	*
Contiguity			*
Not(-consonantal)/Not(+sonorant)		**!	

Shortly after acquiring initial [w], Grace acquires her first clusters at 1;11. The first cluster type produced is obstruent+glide, as in *Grace* [gweɪs] and *sleep* [swip], accomplished by the demotion of **NotComplex(Onset)**, as shown in (186).[191]

(186) Acquisition of obstruent+glide clusters

Input: *Grace* /gɹeɪs/	[gweɪs]	[weɪs]	[geɪs]
NotComplex(Onset)	*		
Co-occurring(Onset→+consonantal)		*	
Survived(-consonantal)			*
Co-occurring(Onset→ -continuant)		*!	
Contiguity			*!
Survived(Place)		*	*
Not(-consonantal)/Not(+sonorant)		**	
Survived(C-Root)		*	*

If this were the only relevant constraint for onset cluster production, its demotion should result in the acquisition of /s/+stop clusters as well, as illustrated in (187), where the constraint rankings incorrectly select cluster preservation.

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[191] The word *blankie* was exceptional, persisting as [wæŋki] until 2;2. This may have been due to other family members referring to it as [bwæŋki] in "baby talk," where initial /b/ was not salient. A pronunciation of [hæŋki] at 1;7 suggests she may have perceived the onset as /w/, since [h] substitution was attested elsewhere for initial glides but not for initial stops or /l/.

(187) Effects of demotion of **NotComplex(Onset)**

Input: *stop* /stap/	[stap]?	[sap]	**[tap]**
NotComplex(Onset)	*		
Co-occurring(Onset→ -continuant)	*	*	
Survived(+continuant)			*
Survived(Place)		*	*
Contiguity		*!?	
Survived(+s.g)			*!?

Since /s/+stop clusters continue to undergo reduction, other sequence constraints must be relevant. With the demotion of **NotComplex(Onset)**, the effects of more specific constraints on sequences of features become evident, preventing production of certain onset clusters while allowing others. The fact that onset clusters are acquired by manner type regardless of place features indicates that constraints against sequences of manner features are relevant within the domain of the onset. In the case of /s/+oral stop clusters, the sequence of obstruents points to a highly ranked **NotTwice(-sonorant)**. Unlike the **NotTwice(+continuant)** constraint used to account for initial fricative deletion in a sequence of [+continuant] consonants, the problem here is not the repetition of a non-default feature, but rather a sequence of two segments that are too close in sonority. This constraint continues to prohibit /s/+stop onset clusters even after **NotComplex(Onset)** has been demoted.

(188) Effects of demotion of **NotComplex(Onset)**

Input: *stop* /stap/	[stap]	[sap]	[tap]
NotTwice(-sonorant)	*!		
NotComplex(Onset)	*		
Co-occurring(Onset→ -continuant)	*	*	
Survived(+continuant)			*
Contiguity		*	
Survived(+s.g)			*
Survived(C-Root)		*	*
Not(+continuant)/Not(+s.g.)	**	**!	

Since this constraint is not relevant for /sN/ clusters, another sequence constraint must be implicated to explain their later acquisition. The fact that these segments differ in nasality points to a highly ranked **NoSequence(-nasal…+nasal)** constraint. In an earlier stage, the effects of this constraint within a syllable were evident in anticipatory nasal harmony in two CVC French words Grace produced, namely *pomme* [mɔm] 'apple' and *peigne* [mɛn] 'comb'.[192] While nasal harmony was eliminated by 1;8 in CVC forms, indicating demotion of this constraint for the syllable domain, the constraint could remain highly ranked within an onset, enforcing persistent /sN/ cluster reduction to the fricative. The use of separate constraints to rule out each cluster type is consistent with the fact that /s/+oral stop and /sN/ clusters are acquired at different times.

Grace's cluster reduction patterns remain stable for several months until 2;4, when she acquires /s/+stop clusters as in *stop* [stap], entailing demotion of **NotTwice(-sonorant)**. Three-member clusters appear very shortly thereafter, as in *stripe* [stwaɪp]. This follows logically from the model's approach to feature sequences, since production of these

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[192] Nasal harmony was also attested in *Grandma* [mæma], though I did not note the data at which nasal harmony ceased in this word. Onset to onset harmony could involve yet another domain for the sequence constraint, as discussed in 3.2.2.

clusters involves the concatenation of sequences already acquired (i.e. /s/+stop and stop+glide). My son Benjamin similarly acquired three-member onsets such as /skw/ in *squirrel* as as soon as he acquired s+stop clusters at 2;8, having already mastered obstruent+glide clusters, and is true of other children as well (Bernhardt and Stemberger 1998: 401).[193]

Once again, Grace's cluster reduction patterns remain stable for a period of time. At 2;9, /sN/ clusters are finally acquired, indicating demotion of **NoSequence(-nasal…+nasal)**. At this point, cluster reduction is eliminated, and the only remaining cluster production errors are due to context-free liquid gliding. Further progress in the acquisition of clusters is simply correlated with the later acquisition of /l/ and /r/.

Importantly, Grace's cluster reduction patterns result from the same basic constraints used to account for initial consonant deletion. Constraints on sequences of features within an onset determined the order of cluster acquisition, with **NotTwice(-sonorant)** causing cluster reduction to persist in obstruent clusters (i.e. /s/+stop) and **NoSequence(-nasal…+nasal)** making /sN/ clusters difficult to acquire. Onset sonority constraints played a significant role in determining which segment was preserved in cluster reduction. Initially, a high ranking of **Co-occurring(Onset→ -continuant)** prevented any fricatives from surfacing in onsets. The later preservation (at 1;10) of the fricative in /sN/ clusters and the stop in /s/+stop clusters as in *stop* [tap] was also due to onset sonority preferences, although it was somewhat more difficult to derive. Since Grace's initial consonant deletion patterns (as analyzed in 5.2.3) led to the conclusion that both **Survived(+continuant)** and **Survived(+s.g.)** applied to /s/ in Grace's grammar, one might expect the fricative to be preserved in both cluster types, since a stop has no applicable **Survived(F)** constraints. However, assuming a high ranking of **Contiguity**, the decision to delete the fricative in /s/+stop clusters fell to lower ranked

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[193] They note, however, that at least some children with phonological disorders have a delay in acquiring three-member clusters after acquiring the relevant two-member clusters, and suggest that this rare pattern could be understood in terms of limited allocation of resources to an onset, placing an upper limit on the number of segments that may appear there (Bernhardt and Stemberger 1998: 401-402).

constraints against the fricative's non-default manner features. In the case of /sN/ clusters, the decision to retain the fricative fell to a lower ranked onset co-occurrence constraint that was not relevant for/s/+stop clusters; namely, lower ranked **Co-occurring(Onset→ -sonorant)**.

Grace's cluster reduction patterns also highlighted the distinction between **Identical** and **Survived** constraints. **Identical(+sonorant)** played a role in preserving nasal stops in singleton onsets despite violation of **Co-occurring(Onset→ -sonorant)**, but was irrelevant in determining which segment to preserve in cluster reduction, a role fulfilled by **Survived(F)** constraints.

6.3 Explaining cluster reduction patterns across children

The constraints relevant in Grace's cluster reduction patterns can help explain general preferences for certain segment types in cluster reduction across children, while still allowing for a wide variety of error patterns attested. Onset sonority preferences appear to be the most important factor in determining which consonant of a cluster is preserved, given the common pattern of preserving the least sonorous consonant. However, these preferences can be trumped by other factors, including **Survived** constraints for non-default features such as [+continuant] or [-consonantal]. If these **Survived** constraints had been ranked higher than the onset co-occurrence constraints in Grace's grammar, fricatives and glides would have been consistently preserved in her cluster reduction. **Contiguity** is another relevant factor, although I am unaware of cases in which this constraint uniquely determines a child's cluster reduction patterns. In terms of the present model, since there are three constraints governing onset sonority preferences, these tend to weigh more heavily in determining the outcome of cluster reduction.

An advantage to the present model is that it does not rely on innate knowledge of a sonority scale for all segments; rather, individual feature-based constraints derived from closed-open cycles of the vocal tract account for sonority preferences. This allows for variation in which featural sonority preferences are most important in a given child's grammar. This can explain the higher degree of variability in cluster reduction preferences for /sN/ clusters, depending on whether the preference for [-continuant] or [-sonorant] is given greater priority in onsets.

While children will vary in their cluster reduction patterns due to different constraint rankings, some patterns are more likely than others for a given cluster type. This is expected based on the number of output constraints favoring preservation of the first versus the second member of a given cluster type, as illustrated in Table 2. For example, in a stop+glide onset, three constraints favor stop preservation, but only one favors glide preservation, explaining why reduction to the stop is the more common pattern. However, a high ranking of **Contiguity** or a featural faithfulness constraint such as **Survived(-consonantal)** can trump the sonority constraints and preserve glides in some children's cluster reduction. For the first three cluster types listed, output constraints clearly favor the less sonorous consonant. For /s/+ sonorant clusters, however, the constraints are not as skewed in favor of one member of the cluster over the other, explaining the higher degree of variation in reduction patterns for these cluster types.

Table 2: Summary of constraints governing cluster reduction
(Shaded boxes correspond to more variability reported)

Cluster type	**Output constraints favoring C1**	**Output constraints favoring C2**	**Potentially relevant faithfulness constraints**
Stop+glide (e.g. /tw, kw/)	Onset→ -sonorant Onset→ -continuant Onset→ +consonantal	Contiguity	Survived(-consonantal)
Stop+liquid (e.g. /pl, kl/)	Onset→ -sonorant Onset→ -continuant Not(+lateral)	Contiguity	Survived(+lateral)
Fricative+stop (e.g. /st, sp/)		Contiguity Onset→ -continuant	Survived(+continuant)
Fricative+nasal (e.g. /sn, sm/)	Onset→ -sonorant	Contiguity Onset→ -continuant	Survived(+continuant) Survived(+nasal)
Fricative+liquid (e.g. /sl, fl/)	Onset→ -sonorant Not(+lateral)	Contiguity	Survived(+lateral)
Fricative+glide	Onset→ -sonorant	Contiguity	Survived(+continuant) Survived(-consonantal)

This approach to /s/ cluster reduction patterns contrasts with several recent analyses, all of which appeal to special treatment of /s/, either as a syllable adjunct (Gierut 1999, Barlow 2001, Jongstra 2003, Goad and Rose 2002) or its perception by children as an unstressed degenerate syllable (Kwon and Stanford 2006). Some researchers do not consider /sC/ onsets to form a "true cluster" (e.g. Gierut 1999, Baertsch and Davis 2003). However, if a special structure places initial /s/ outside of the syllable onset, this seems to predict that children should acquire all /s/-initial sequences in the same manner. That is, once they have acquired the adjunct structure, all /s/-initial sequences should be equally possible. This is clearly not the case for Grace, whose acquisition of /s/ clusters proceeded in three different stages, indicating no special status for the initial /s/. The treatment of /s/ as a syllabic adjunct in Goad and Rose (2004) also requires that the child receive some kind of evidence in the input for the special structure associated with /s/. It is not clear what would constitute such evidence or how a child would acquire this knowledge.

There are other ways in which /s/-initial clusters pattern with other clusters, suggesting that there are no structural differences. Stemberger and Treiman (1986) found that consonants in the second position of an onset had higher error rates than those in first position, regardless of segmental identity (a phenomenon they attributed to lower activation levels in second position). Stemberger and Bernhardt (1999) also note an interesting restriction in CCVC English words on repetition of non-default place and manner features in the second consonant of an onset cluster and the final consonant. Note that this constraint does not hold over repetition of the default place feature [Coronal], given forms like *state* [steɪt] and *stat!* [stæt].

(189) **NotTwice(Non-default)** constraint in English CCVC words
C_iVC_i sequences allowed: [ɹɛɹ] [lʌl] [mam] [pap]
$C\mathbf{C}_iV\mathbf{C}_i$ sequences disallowed: *[kɹɛɹ] *[plʌl] *[smam] *[spap]

This constraint apparently holds over the second and final consonant of a word with any licit English onset cluster, regardless of whether it is /s/-initial, indicating no special treatment or structure for /s/-initial clusters.

An advantage of the present model is that it can accommodate a wide variety of patterns. While sonority often selects stop preservation in /s/+stop clusters, /s/ preservation is preferred by some children. This can be easily attributed to a high ranking of **Survived(+continuant)**.

The applicability of **Survived** constraints for non-default features such as [+continuant], Labial, [+nasal], and [+s.g.] helps explain common coalescence patterns. The predominance of labial fricatives in coalescence (e.g. *spider* [faɪdə]) is expected, since both [+continuant] and [Labial] should survive in the output if possible. Velar fricatives are not similarly common in English cluster reduction since English lacks velar fricatives.[194] The occasional appearance of voiceless nasals for /sN/ clusters as in *smile* [m̥aɪʊ] is also predicted by this approach, given the applicability of **Survived(+nasal)** for nasals and, at least in some children, **Survived(+s.g.)** for fricatives. Finally, **Survived(F)** for non-default features helps explain why non-coronal segments are more likely to be preserved in a cluster than coronal segments, e.g. /sp/→ [p] but /st/→ [s] (Amahl, Smith 1973).[195] Interestingly, the promotion of **Survived(Dorsal)** appeared to assist in one child's sudden acquisition of /sk/ clusters. Megan produced target /st/ clusters sporadically over a two-month period from 3;10-4;0 before acquiring them consistently (Ringo 1985). By contrast, correct productions of /sk/ clusters were first observed at 3;11.25 and reached 100% just two days later.

Finally, the present model can also help explain the typical order of acquisition of various cluster types. Stop+glide is typically the first cluster type acquired, e.g.

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[194] The prohibition on velar fricatives in English and in most English-acquiring children can be attributed to highly ranked **NotCo-occurring(Dorsal,-sonorant,+continuant)**).

[195] Determining the specific ranking that led to this pattern would require researching additional details of his phonological system at the particular stage during which this pattern was attested.

/tw,kw/ (Smit 1993) or /kw/ in particular (Wellman, et al. 1931, cited in Chin and Dinnsen 1992). This cluster type is ideal for many children because it fulfills all onset sonority co-occurrence constraints and maximizes sonority contrasts within the onset, avoiding violations of **NotTwice(-sonorant)**, **NotTwice(+continuant)**, and even **NotTwice(+consonantal)**. At the same time, the set of constraints on sequences of features allows for the range of order of acquisition of specific cluster types. For example, while stop+glide clusters are often the first clusters acquired, a child with a high ranking of **NoSequence(-continuant…+continuant)** could find this sequence difficult. In addition, **NoSequence(Coronal…Labial)** could prohibit /tw/ clusters, explaining why some studies report /kw/ rather than /tw/ as the first cluster acquired, as well as why some children's first clusters include [fw] clusters (Smit 1993). For a /tw/ onset, a coronal stop followed by a labio-velar glide may be difficult due to **NoSequence(-continuant…+continuant)** and **NoSequence(Coronal…Labial)**. If both segments are preserved due to **Survived(C-Root)** and/or **Survived(Place)**, **Identical(+continuant)** will favor preservation of [+continuant] and **Survived(Labial**) will favor labial preservation, resulting in /tw/→ [fw].[196]

All of these cluster reduction patterns point to the crucial role of constraints on sequences of features in the acquisition of onset clusters. The premise that sequence constraints are related to speech planning and may be restricted to the syllable onset is supported by reports that consonant sequences prohibited in onsets may be produced faithfully elsewhere. Megan simplified medial clusters that could be syllabified as onsets (e.g. *asleep* [asip], *sister* [sɪsə]) but did not simplify consonant clusters occurring across a word boundary, as in *this toe* or *this man* (Ringo 1985). Similarly, for two-year-old "Buddy," the sequence /st/ was prohibited within a syllable onset as in *stop* [tap] and *beanstalk* [bijntɔk], but not word-medially as in *nice treat* [najs twijt], where the consonants belong to different syllables (Greenlee 1973).

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[196] At 2;7, my son Benjamin produced /sw/ onsets as [fw], indicative of highly ranked **NoSequence(Coronal…Labial)** and labial spreading.

This discussion of cluster reduction trends has been limited English onset clusters. It would be interesting to examine cluster reduction data from languages with other cluster types (e.g. Polish or Greek) to determine the role of other constraints on sequences of features and how these affect order of acquisition in languages with additional cluster types. Due to limits on the scope of this dissertation, this must be left for future research.

7 Concluding thoughts

"Accounting for phonological acquisition is a formidable task."
--David Ingram, *First Language Acquisition*, 1989: 383

This longitudinal study of an English-acquiring child from 1;1–2;9 afforded a unique window into the role of consonant harmony, metathesis, and initial consonant deletion in phonological development. An advantage to this type of study is that each process is placed in the context of the child's phonological development, providing a better understanding of how these processes evolve and are eliminated. The progression of error patterns over time sheds further light on the role of each process in the developing system. At the same time, the nature of the study presented a unique challenge for the data analysis. For any given process analyzed in isolation, there may be multiple ways of deriving the data with constraint rankings. In the context of a child's complete phonological system, however, the proposed constraint rankings must conspire to produce multiple concurrent error patterns. In addition, the plausibility of changes in constraint rankings from one stage to the next must be considered. This made it particularly challenging to arrive at a workable analysis for all of the data.

The Bernhardt and Stemberger (1998) constraint-based model was well suited for the analysis of Grace's longitudinal data. By positing constraints against all features of a segment, as well as production of these features in combination and in sequence with other features, the model reflected the fact that production of any segment requires articulatory effort and the use of cognitive resources in speech planning. Its unique view of default underspecification incorporated the role of frequency in determining the default value of each feature. Since constraints against default feature values are consistently ranked lower than those against the corresponding non-default, defaults may be underspecified, since they will surface by default in the absence of any other feature specification. By positing faithfulness constraints promoting the survival of each element of a consonant, including its C-Root node, Place node, and contrastive non-default features, the model permits a cost-benefit analysis weighing the relative cost of producing a segment against the relative benefit in terms of faithfulness, which proved key to deriving Grace's initial consonant deletion patterns. In order to provide the most explanatory account of the data, I adapted the Bernhardt and Stemberger (1998) model in several ways, including the addition of a Lingual feature node to the feature hierarchy; a distinction between constraints on sequences of features that favor feature agreement and constraints disfavoring feature repetition; expansion of the faithfulness constraint set to include a distinct role for **Identical** constraints; refining definitions of onset sonority constraints to apply only to segments with vocal tract constriction, and the use of a constraint against initial dorsals.

An advantage of this model is its flexibility, given the number of production and faithfulness constraints applying to each segment. A challenge inherent in the model is its complexity. For each process, it was essential to consider every relevant constraint against the features of the segment in question and the context in which those features were produced. While the derivations were not always simple, this may simply reflect the fact that phonological processing is complex, as is much of human behavior.
I conclude that the complexity of the model is a small price to pay for its comprehensiveness and ability to explain a wide variety of attested error patterns.

Grace's longitudinal data highlighted several important factors in the acquisition of consonant sequences, including three types of constraints on sequences of features. **Agree** constraints such as **Agree(C-Place)** and **Agree(Lingual)** disprefer sequences of consonants differing in a given feature or feature node and are grounded in speech planning considerations. These constraints can motivate either consonant harmony or deletion, depending on the ranking of other faithfulness constraints, since both processes can eliminate an offending sequence. When an **Agree** constraint motivates harmony, it typically results in bidirectional harmony over coronals, since assimilation must occur regardless of feature ordering. **NoSequence** constraints, by contrast, disprefer particular feature orderings, such as **NoSequence(Dorsal…Labial)**, and can therefore motivate harmony, deletion, or even metathesis, if the reverse sequence has already been acquired. Again, the particular response to this constraint depends on the ranking of other constraints. **NotTwice** constraints such as **NotTwice(+continuant)** prohibit the repetition of a feature within a prosodic domain, and can be grounded either in a dispreference for producing two non-default features in sequence or in sonority considerations preferring aperture contrasts in adjacent segments.

Onset sonority preferences also play a significant role in the acquisition of consonant sequences, especially related to initial consonants and onset clusters. The Bernhardt and Stemberger (1998) feature-based approach to these constraints, grounded in the maintenance of closed-open cycles of the vocal tract, provides more flexibility in the model than positing a fixed sonority hierarchy. The presence of separate constraints preferring [-continuant], [-sonorant], and [-consonantal] features in onset position allows the model to derive a variety of initial consonant deletion and cluster reduction patterns. Since Grace permitted initial [h] to surface despite high rankings of **Co-occurring(Onset→ +consonantal)** and **Co-occurring(Onset→ -continuant)**, I concluded that these constraints are specifically relevant for consonants with vocal tract constriction (preferring that this constriction be as closed as possible in onset position), and refined the definition of these constraints accordingly.

A constraint against initial velars can also be relevant in the acquisition of consonant sequences. While Bernhardt and Stemberger (1998) posit a co-occurrence constraint preferring [Dorsal] features in rimes, I reformulated the constraint in the negative as **NotCo-occurring(Onset,Dorsal)** (following Fikkert and Levelt 2008 and Morrisette et al. 2003) in order to account for the data. Proposed in other analyses to account for positional velar fronting patterns in acquisition (e.g. *cook* [tʊk]), this constraint was seen to be relevant in dispreferring anticipatory velar harmony and favoring initial consonant deletion in certain sequences. In addition, it may play a role in preferring metathesis over consonant harmony when an initial velar is involved, accounting for the propensity of Dorsal…Labial and Dorsal…Coronal sequences to undergo fronting metathesis.

Another significant factor in predicting harmony and deletion patterns is the tendency in speech planning to anticipate the next feature in the prosodic domain, generally favoring anticipatory harmony and more specifically making Default…Non-default sequences of features (such as Coronal…Labial) more challenging to acquire. The anticipatory nature of speech planning is reflected in the model in two ways. One is a constraint placing priority on preservation of the last feature or feature node in a sequence (within a prosodic domain) when both cannot be preserved due to sequence constraints, e.g. **Priority(C-Place,Last)**. I also proposed a fixed higher ranking of **NoSequence(Default…Non-default)** type constraints over the reverse, **NoSequence(Non-default… Default)**, a ranking that emerges as children develop the speech planning skills necessary for successful language production.

The fact that children must learn to coordinate all feature sequences explains why harmony is typically bidirectional in the early stages. Grace's earliest stage, for example, was characterized by a highly ranked **Agree(C-Place)** constraint prohibiting any sequence of differing consonant place features. This constraint motivated harmony (and initial consonant deletion) but not metathesis, since the ordering of features was irrelevant. The tendency for coronals to undergo harmony was seen to follow from default underspecification, where [Coronal] is the underspecified default place feature. In a prohibited sequence of features, **Survived** constraints for the non-default place features [Labial] and [Dorsal] lead to labial or velar harmony over coronals.

The presence of **Survived** constraints also helps explain why Dorsal…Labial sequences are particularly susceptible to long-distance metathesis as in *cup* [pʌk], since metathesis permits preservation of both non-default place features. Metathesis emerged only briefly in Grace's phonological development, since **Agree(C-Place)** initially prohibited all sequences of different place features. The demotion of **Agree(C-Place)** revealed the relative ranking of **NoSequence** constraints against specific orderings of features such as **NoSequence(Lingual…Labial)**. Metathesis occured only for underlying Dorsal…Labial sequences since **Agree(Lingual)** prohibited any sequences of different lingual consonants, and Coronal…Labial sequences underwent harmony instead due to coronal underspecification.

The most interesting and significant data examined relates to initial consonant deletion patterns, the least well understood of the child-specific processes analyzed here. While it has been suggested that initial consonant deletion is rare and idiosyncratic, my survey of available reports of initial consonant deletion in eight different languages indicates that it is not as uncommon as previously thought and tends to affect initial continuants or target sequences of different consonants. Grace's data provided examples of both types of initial consonant deletion. Initial /h/ and stop deletion in a consonant sequence were eliminated first as she acquired place and manner feature sequences. Initial fricative and glide deletion persisted due to highly ranked onset sonority constraints and a **NotTwice(+continuant)** constraint against repetition of [+continuant] within a syllable.

The progression of Grace's initial consonant deletion patterns from one stage to the next suggested that learning proceeds via both demotion of output constraints and promotion of faithfulness constraints. Generally, her grammar placed a higher priority on faithfulness to manner than place features for initial continuants, explaining the propensity for deletion or [h] substitution as opposed to stop substitution. The promotion of **Survived(Place)** was key in her acquisition of initial fricatives and glides, allowing onset sonority preferences to play a continuing role in her cluster reduction patterns.

The particular initial consonant error patterns in Grace's data led to the somewhat unexpected conclusion that voiceless fricatives were underlyingly specified for [+s.g.] in her grammar, in addition to being specified for [+continuant]. This in turn led to the conclusion that /h/ must be underlyingly specified not only for [+s.g.], but also for [-consonantal]. In this way, **Survived(+s.g.)** and **Survived(-consonantal)** both applied to underlying /h/ and helped account for its preservation in certain contexts. Both of these assumptions were crucial to explain her error patterns and changes from one stage to the next.

Grace's initial consonant deletion patterns also provided evidence for the distinct roles of two previously proposed types of faithfulness constraints. **Survived** constraints (cf. MAX) mandate the preservation of contrastive, non-default features that are underlyingly specified in the lexicon. These constraints reflect the strength of the connections to the non-default features specified in the underlying representation and are equally violated by deletion and featural substitution. **Identical** constraints, on the other hand, serve to evaluate the identity of a potential segmental substitute with respect to a non-default features associated with a segment and are vacuously satisfied by deletion. For example, although [+sonorant] is predictable for nasals, glides, and laterals, **Identical(+sonorant)** prevents changes in this feature in the output, which helped explain a stage in which initial laterals were deleted rather than being substituted by an oral stop. In addition, the fact that fricative stopping was never optimal required a highly ranked **Identical(+continuant)** constraint. Importantly, these constraints do not help preserve the segment itself, thereby permitting segmental deletion under certain circumstances.

The role of sequence constraints and onset sonority preferences was also evident in Grace's cluster reduction patterns. While an undominated **NotComplex(Onset)** constraint could account for the initial stage in which all onset clusters were prohibited, more specific constraints against sequences of features were required to explain the acquisition of different cluster types at different times. **NotTwice(-sonorant)** prohibited obstruent clusters until 2;3, and **NoSequence(-nasal…+nasal)** prohibited /sN/ sequences until 2;9. Importantly, the constraint rankings proposed for Grace's initial consonant deletion patterns also accounted for her concurrent cluster reduction patterns, emphasizing the conspiratorial nature of a constraint-based model.

Grace's cluster reduction patterns provided additional evidence for the two types of faithfulness constraints. **Survived** constraints, which mandate the preservation of a feature in the output, were relevant in determining which non-default features should be preserved in cluster reduction. **Identical** constraints for predictable non-default features such as **Identical(+sonorant)**, though highly ranked, were not relevant in determining feature preservation in cluster reduction, since they only evaluate the suitability of a substitute segment. This distinction was crucial in accounting for a stage in Grace'e development in which preservation of the fricative was preferred over the nasal in /sN/ cluster reduction.

The child-specific processes of consonant harmony, long-distance metathesis, and initial consonant deletion are all typically eliminated prior to the elimination of cluster reduction. This led me to the conclusion that consonant feature sequences must be acquired first within a word (across a vowel) before they are acquired for immediately adjacent sequences, explaining the progression in phonological development from long-distance to local assimilation and metathesis. Given that the sequence constraints are defined for both consonant tier and root adjacency, this progression is expected, since root adjacency entails tier adjacency but not vice versa. That is, if a sequence occurs in adjacent consonants, it also occurs within the word, while the converse is not true. If feature sequences must be acquired on the consonant tier first, this provides a natural explanation for the fact that CVC consistently precedes CCV syllable acquisition, a pattern that is not predicted by the standard constraints NOCODA and *COMPLEX (McCarthy and Prince 1995), which are freely re-rankable.

Constraints on sequences of features and onset sonority preferences were seen to be the most important factors in motivating early consonant harmony, long-distance metathesis, and initial consonant deletion, with a constraint against initial dorsals playing a lesser role. Importantly, this analysis permits continuity of constraints in phonological development. The constraints that conspire to produce these early processes do not disappear in the course of acquisition. Rather, the increased faithfulness demands of acquiring a fully developed language require children to overcome these restrictions in order to express the full range of lexical contrasts of the adult language. The effects of these constraints, however, may still be observed in a number of different ways.

Onset sonority preferences are uncontroversially observed in adult languages. The tendency to anticipate the second feature of a sequence is evident in anticipatory harmony and assimilation patterns in adult phonology, as well as in speech errors. Sequence constraints may be implicated in cluster reduction patterns, as discussed in 6.3. They may also play a role in phonological processes affecting immediately adjacent sequences, motivating assimilation of adjacent consonants in some languages, as in Korean /ip+ko/ [ikko] (de Lacy 2002), and motivating metathesis in other cases, as in Kui /bluk+pa/ [blupka] (Hume 2004).

On the consonant tier, the effects of constraints on feature sequences can be seen in the consonant harmony patterns of mature languages (Hansson 2001). As the child's speech planning skills improve, the effects of these constraints on the consonant tier are limited to lower nodes in the place hierarchy, affecting minor rather than major place features. Thus coronal and dorsal harmony systems can be attributed to **Agree(Coronal)** and **Agree(Dorsal)** constraints, while asymmetric anticipatory harmony patterns can be explained by **NoSequence** constraints for Default…Non-default sequences.

Long-distance co-occurrence restrictions for laryngeal feature sequences in adult languages provide additional evidence for all three types of sequence constraints proposed here. According to a survey in Gallagher (2010), languages may exhibit either assimilatory or dissimilatory patterns with respect to sequences of laryngeal features within a word. Some languages disallow consonant sequences with differing laryngeal features (e.g. *[k'apa]), resulting in assimilation to the marked laryngeal feature (e.g. [k'ap'a]. Other languages disallow precisely the opposite sequence type, i.e. a sequence of two marked laryngeal features (e.g. *[k'ap'a]), which can result in the opposite process of dissimilation. Some dissimilatory languages exhibit an additional restriction on sequences, such that a marked laryngeal feature may appear only in initial position when followed by a stop. The attested patterns are summarized in (190), where the notation K-T stands for any sequence of stops, and an apostrophe stands for a marked laryngeal feature (ejection, aspiration, or implosion).

(190) Laryngeal feature sequence co-occurrence restrictions (Gallagher 2010)

a.	Assimilatory languages:		*K′ – T, *K – T′, neutralized to K′ – T′
b.	Dissimilatory languages:		*K′ – T′
		Pattern A:	Allows K′ – T or K – T′
		Pattern B:	Allows only K′ – T, not *K – T′

Gallagher (2010) notes that these contradictory patterns are a challenge for standard markedness constraints, and pursues instead a perceptually based account based on contrast preservation within a language system. However, these patterns can also be understood in terms of the sequence constraints used here in the analysis of Grace's data. Assimilation can result from a highly ranked **Agree(Laryngeal)** constraint disfavoring a stop sequence with differing laryngeal features, where default underspecification predicts assimilation of plain stops to the non-default laryngeal feature. Dissimilatory languages, on the other hand, can result from a high ranking of a **NotTwice(F)** constraint prohibiting repetition of a non-default laryngeal feature. The additional *K – T′ sequence restriction in some languages can be attributed to a highly ranked **NoSequence** constraint, following the typical pattern disfavoring Default…Non-default type sequences (as discussed in 4.1.2).

The effects of the proposed constraint against initial velars are perhaps less obvious in adult languages. However, the low frequency of initial velars in a variety of modern languages surveyed[197] and the lack of initial velar nasals in numerous European, Asian, Siberian, and Native American languages[198] both point to a dispreference for [Dorsal] in initial position. Articulations in music also provide examples of "emergence of the unmarked" with respect to initial velars. For example, initial velars are typically avoided in the choice of nonsense syllables in singing, where labials and coronals are

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[197] Initial velars were least frequent in English, Dutch, German, French, Italian, Spanish, Czech, Polish, Hungarian, Finnish, and Yoruba, but not Swahili (Janda 1979, cited in Locke 1983).

[198] Of 234 languages with a phonemic velar nasal, 88 lack it word-initially (Anderson 2008).

favored, e.g. [dʌm di dʌm] or [ba ba ba bada bada]. In nonsense syllables where velars do appear, they are typically word-medial, e.g. [dɪgʌ dɪgʌ dɪgʌ]. This preference is also seen in the musical technique of "flutter tonguing" used by musicians who play instruments requiring tongue articulation, such as the flute. Typically, a coronal tonguing technique is used, as in [tu.tu.tu.tu]. However, for very rapid musical passages, tongue articulations alternate between the two major lingual places of articulation, as in [tu.ku.tu.ku.tu.ku]. Significantly, such sequences always begin with the coronal place of articulation, never the velar.

With this set of independently grounded constraints and a better understanding of patterns of initial consonant deletion in acquisition, it is possible to provide a principled explanations for these processes that are limited to early phonological development without resorting to child-specific constraints or relying on child-specific fixed constraint rankings with respect to prominence. The longitudinal data examined here demonstrate that changes in faithfulness constraint rankings and a limited set of independently grounded production constraints can conspire to produce all three child-specific processes in a single child's phonological acquisition.

Finally, the longitudinal data had implications for the essential aspects of a constraint-based model. Based on the changes in Grace's initial consonant deletion patterns over time, a successful model should allow both for demotion of production constraints and promotion of faithfulness constraints, modeling the fact that learning takes place both by improvements in speech planning skills and by an increasing emphasis on faithfulness to all of the contrastive features of the adult language. The data also provided evidence for a principled distinction between **Survived** (cf. MAX) and **Identical** constraints, suggesting that both types of faithfulness constraints are necessary in a comprehensive phonological model. The implications of these distinctions may be relevant for explaining other deletion data from acquisition or loanword phonology, both of which are promising areas for future research.

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Appendix A: Definitions

Features

The following list is not exhaustive, but limited to those features relevant for the analysis in this dissertation. Definitions are taken from Bernhardt and Stemberger (1998: 697-703).

Laryngeal features

[+voiced]:	Any sound produced with vocal cord vibration (obstruent or sonorant).
[+spread glottis]:	Sounds produced with the vocal cords spread wide, leading to low-amplitude noise at the glottis.

Manner features

[+sonorant]:	Sounds in which the pressure above the larynx allows the vocal cords to vibrate continuously, without any rise in pressure above the larynx. Obstruents (stops, fricatives, and affricates) are **[-sonorant]** because the constriction inhibits airflow sufficiently to cause a rise in supraglottal pressure. According to this definition, [h], which is essentially a [+s.g.] vowel, is [+sonorant] since there is no supraglottal constriction.
[+consonantal]:	Sounds with a narrow constriction in the oral and/or pharyngeal cavities that significantly impedes the flow of air, either by stopping it, redirecting it, or creating turbulence. Vowels, glides, and glottals are **[-consonantal]** since airflow is unimpeded.
[+continuant]:	Sounds in which air continues to move through the oral cavity (and possibly just over the constriction). Vowels, glides, liquids, and fricatives are [+continuant]. Stops and affricates, including nasal stops and glottal stops, entirely block oral airflow and are **[-continuant].** Nasals are [-continuant] since airflow continues only through the nasal cavity. Languages and individuals may differ in their treatment of laterals with respect to [continuant], since airflow continues over the sides of the tongue but is blocked at the constriction.
[+nasal]:	Sounds with the velum lowered so that air moves through the nasal cavity.
[+lateral]:	Sounds in which central airflow is blocked in the oral cavity, but in which air is directed over at least one side of the tongue.

Place features

[Labial]:	Sounds made with some involvement of one or both lips. Since this is a privative feature, any segment that is not [Labial] is blank for this feature. For both vowels and consonants, all rounded segments are [Labial].
[Coronal]:	Sounds made with raising of the tip or blade of the tongue. This includes interdentals, dentals, alveolars, palato-alveolars, alveo-palatals, retroflexes, and palatals (which are also [Dorsal]).
[Dorsal]:	Sounds made with the back of the tongue. Palatals, velars, uvulars, and pharyngeals are [Dorsal], as well as all vowels.

[+back]:[199]	Sounds with the back of the tongue body raised or lowered. Velar and uvular consonants and back and central vowels are [+back], while palatal consonants and front vowels are [-back].

Constraints

The following is not an exhaustive list of constraints, but is limited to those relevant for the analysis in this dissertation.

Production constraints

Not:	An element (i.e. feature, timing unit, or other prosodic structure) must not appear in the output; e.g. **Not(+nasal)**, **Not(Dorsal)**, **Not(C)**, **Not(Coda)**.
SinglyLinked:	A feature can be linked to only a single higher element in the geometry (i.e. do not spread a feature beyond its basic duration); e.g. **SinglyLinked(Dorsal)**.
NotCo-occurring(A,B):	A and B may not co-occur at the same point in time; (such as within the same segment; e.g. **NotCo-occurring(Labial,Dorsal)**.
NoSequence(A…B):	Given two adjacent segments, A cannot be in the first segment if B is in the second segment; e.g. **NoSequence(Labial…Dorsal)**.
NotTwice(F):	A feature F may not appear twice in a sequence of adjacent segments. May be highly ranked for aperture features due to sonority sequencing preferences, e.g. **NotTwice(-sonorant)**. May also be highly ranked for any non-default feature, due to the additional resources required to produce a non-default feature twice in a sequence, e.g. **NotTwice(+continuant)**.
Agree(F):	A sequence of segments differing in the feature F is prohibited, e.g. **Agree(C-Place)**, **Agree(voice)**.
Co-occurring(A→B):	The presence of A implies B. Primarily used in this dissertation to express onset sonority co-occurrence preferences, e.g. **Co-occurring(Onset→ -sonorant**), which states that a syllable onset segment should be [-sonorant]. As discussed in Section 5.2.3, I restrict onset sonority constraints to onset segments with a place node due to the evidence that glottals are exempt. Additional onset sonority preferences are expressed by the constraints **Co-occurring(Onset→ +consonantal)** and **Co-occurring(Onset→ -continuant)**.
Uninterrupted (F):	A feature must be linked to all segments within the span of its spread (no segments may be skipped); e.g. Uninterrupted (+voice) (favors intervocalic voicing).

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[199] Dorsals may be further defined for the features [high] and [low]; however, I do not need this level of detail for the present analysis.

Faithfulness constraints

Survived:	An element in the underlying representation must be present in the output, e.g. **Survived(Dorsal)**, **Survived(C-Root)**, **Survived(Link)**. Given default underspecification, a **Survived** constraint applies for each contrastive non-default feature.
Identical(F):	Correspondent segments should have identical values for a non-default feature F. May apply to predictable non-default features, including [Lingual].
Contiguity:	Elements that are contiguous in the underlying representation must be contiguous on the surface.
Linearity:	The precedence order of elements in the input must be respected in the output.
Priority(Last, X):	The last element X in a given prosodic domain has priority.

Appendix B: Complete data transcriptions, 1;1-1;11

1;1
uh-oh [ʔʌʔoʊ]
oh (*Cheerios*) [oʊ]
mama [mama]
banana [nænæ]
Daddy [dæi]

1;2
bread [bɛ]
bottle [ba]
avocado/fruit [gai/gɔgi] (*variable*)

1;3
kitty [kɪi]
meow [ʔaʊ]
cheese [ts]
hi [haɪ]
bye [baɪ]
go [goʊ]
cracker [kækə]

1;4
dinde (*Fr.*) [næn] 'turkey'
pain (*Fr.*) [pa] 'bread'
"boop" [bʊp]
ball [ba]

1;5
*cheese [tsis]
milk [ɛʊk]
cookie [kʊk:i]

1;6
coat [kɔk]
pomme (*Fr.*) [mɔm] 'apple'
hello [haʊ]
Pooh [pu:]
"*clic*" (*Fr.*) [kik]
Elmo [ɛʊmo]
thank you [ʌŋku]
baby [bibi]

1;6, cont.
juice [ʊs]
blankie [ʌŋki]
please [is]
hat [æt]
key [ki:]
that [dæt]
boat [boʊ]/[boʊp]
blow [boʊ]
me [mi:]
Blue [bu:] (*dog*)
help [ʌʊp]
out [aʊʔ]
fish [ɪs]
poupée (*Fr.*) [pupi] 'doll'
bumpy [bʌpi]
read [i:]
snake [eɪk]
bunny [mai]
doggy [dai]
cook [kʊk]
cut [kʌk]
hop [hap]
light [aɪʔ]
sky [kaɪ]
book [oʊk]
splash [pas]

1;7
*cheese [kis] (*apparent regression*)
*milk [nɪʊk]
**pomme* (*Fr.*) [pɔm]
*blankie [hæŋki]
*please [pis]
*hat [hæt]
*boat [boʊt]
*help [hʌʊp]
*bunny [bai]
*doggy [gagi]
*book [boʊk]
duck [ʌk]
hot [hat]
watch [hat]
piano [mao]

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* An asterisk indicates a change in pronunciation of an existing word.

1;7, cont.
tomate (*Fr.*) [mat] ‘tomato’
pâtes (*Fr.*) [pat] ‘pasta’
sock [hak]
caca (*Fr.*) [kaka] ‘poopie’
peigne (*Fr.*) [men] ‘comb’
woof (dog) [ʊɸ]
“bawk” [bak] (chicken)
“bonk” [bak]
bug [bʌk]
pêche (*Fr.*) [pɛs] ‘peach’
ant [æt]
puppy [pʌpi]
cow [kaʊ]
pool [pu:]
broccoli [baki]
monkey [mʌki]
mouse [maʊs]
house [haʊs]
egg [ɛk]
bike [baɪk]
grape [beɪk]
brush [bʌs]
bag [bɛk]
couche (*Fr.*) [kus] ‘diaper’
glasses [gas]
kick [kɪk]
grandpa [bæpa]
grandma [mæma]
toast [toʊt]
toes [toʊs]
bowl [boʊ]
apple [æpoʊ]
eat [it]
boots [buts]
map [mæp]
mine [maɪn]
cake [keɪk]
deer [gi]
no! [noʊ]

1;8
*bread [bɛt]
**dinde* (*Fr.*) [dæn]
*juice [dus]
*snake [neɪk]
*duck [dʌk]

1;8 (cont.)
*piano [pao]
*deer [di]
corn [kojn]
down [daʊn]
done [dan]
pen [pɛn]
clock [kak]
car [kaj]
rain [eɪn]
ride [aɪt]
nose [noʊs]
spider [paɪ]
pig [pɪk]
night [naɪt]
cold [koʊk]
toy [taj]
cry [kaɪ]
push [pɪs]
those [doʊs]
again [gɛn]
play [peɪ]
here [hi]
ten [tɛn]
horse [hoʊs]
kitchen [tɕɪtɕən]
run [ʌn]
up [ʌp]
truck [kʌk]
spoon [pu:n]
button [bʌtən]
cup [pʌp/pʌk]
doudou (*Fr.*) [doʊdoʊ] ‘blankie’
chicken [kɪkɛn]
open [opɛn]
goose [gus]
kiss [kɪs]
(patates) douces (*Fr.*) [dus] ‘sweet potatoes’
dog [dak]
(mini-)wheats [its]
concombre (*Fr.*) [kuku] ‘cucumber’
close [koʊs]
cat [kæt]
yaourt (*Fr.*) [aʊt] ‘yogurt’
mess [mɛs]
train [teɪn]
crane [keɪn]

1;8 (cont.)
head [hɛt]
get [gɛt˺]
fraise (*Fr.*) [ɛs] ‘strawberry’
shoes [us]
pants [pæt]
eyes [aɪs]
bus [bʌs]
Luke [uk]
au lit (*Fr.*) [o i] ‘in bed’
bad guy [gæg:aɪ]
plate [peɪt]
happy [hæpi]
bath [bæɸ]
noise [nɔɪ]
(raisin) sec (*Fr.*) [hɛk] ‘raisin’
walk [hak]
rock [hak]
mouth [maʊs/ɸ]
home [hom]
hide [haɪt]
touch [tʌts]
bouche (*Fr.*) [buʃ] 'mouth'
game [gɪŋ]
Max [mæk]
(*un*)*oeuf* (*Fr.*) [mœɸ] ‘an egg’
pocket [pa:kɪt]
door [dɔj]
wipe [haɪp]
knock [nak]
knock-knock [nanak]
stuck [tʌk]
stick [tɪk]
wake (up) [eɪk]
reach [itɕ]

1;9
*coat [koʊt]
*grape [geɪp]
*cup [kʌp]
**concombre* (*Fr.*) [kõkõ]
*Luke [duk]
*wake (up) [kʌp]
chip [tʌp]
straw [ta]
wash [aʃ]
marche (*Fr.*) [maʃ] ‘step’
sleep [hip]

1;9 (cont.)
backpack [pæbæk]
bandaid [bætaɪt]
get up [dʌp]
snap [næp]
stop [tap]
cage [keɪdʒ]
nice [naɪs]
see [si]
flower [ɸawaj]
orange [ʌndʒ]
surprise [paɪs]
yucky [jʌki]
cloche (*Fr.*) [kɔʃ] ‘bell’
captain [kæt:ən]
climb [kaɪm]
catch [kɛtʃ]
pear [peɪ]
circle [sikoʊ]
step [tɛp]
quatre (*Fr.*) [kæt] ‘four’
five [ɸaɪɸ]
crib [kɪp]
owie [awi]
hurt [hət]
throw [ɸoʊ]
soap [sop]
soup [sup]
drop [dap]
moon [mu:n]
arm [am]
water [jai]
Raja [jaʒa] (*cat’s name*)
rice [jaɪs]
upstairs [ʌptejs]
Ben [bɛn]
enough [nʌɸ]
giraffe [jæɸ]
raccoon [ku:n]
sorry [sai]
couch [kaʊtʃ]
happen [hæpən]
flute [ɸut]
chair [tʃej]
yummy [jʌmi]
snack [næk]
spaghetti [gɛi]
sit [sɪt]

1;10

*_fraise_ (_Fr._) [ɸɛs]
*_shoes_ [ʃus]
*_sec_ (_Fr._) [sɛk]
*game [gaɪm]
*(_un_)_oeuf_ (_Fr._) [nœɸ]
*wipe [jaɪp]
*chip [tʃɪp]
*wash [jaʃ]
*sleep [sip]
*snap [sæp]
*snack [sæk]
big [bɪk]
yeah [jæ]
know [noʊ]
lion [jaɪn]
blood [bʌt]
sound [saʊn]
doll [daː]
dance [dæts]
tower [tawʊ]
mango [mẽgoʊ]
bagel [beɪgoʊ]
(I) "do it" [duɪt]
(what are you) doing? [duɪŋ]
shortcake [ʃoʊk:eɪk]
guitar [taː]
change [tʃẽtʃ]
cereal [ʃioʊ]
whole piece [hoʊs pis]
napkin [næk:ɪn]
picture [pɪtʃə]
off [aɸ]
triangle [tʃaĩgoʊ]
crash [kæʃ]
Grace [geɪs]

1;11

*cheese [tʃis]
*cracker [kwækʊ]
*blankie [wæŋki]
*please [pwis]
*read [wit/widə]
*snake [seɪk]
*bug [bʌgə]
*broccoli [bwaki]
*grape [gweɪp]

1;11, cont.

*bag [bɛgə]
*glasses [gwæs]
*Grandpa [gwæpa]
*kitchen [kɪtʃən]
*run [wʌn]
*chicken [tʃɪkɛn]
*(mini-)wheats [wits]
*Luke [wuk]
*plate [pweɪt]
*wipe [waɪp]
*wake up [weɪkʌp]
*wash [waʃ]
*flower [ɸwawʊ]
*water [waə]
*Raja [waʒa]
*crash [kwæʃ]
*Grace [gweɪs]
joli (_Fr._) [ʒoi] 'pretty'
shower [ʃawʊ]
yellow [jɛw]
green [gin/gwin]
clean up [kinʌp/kwinʌp]
foot [ɸʊt]
bib [bɪp]
towel [taʊ]
spill [pɪʊ]
castle [kæsəw]
shirt [ʃut]
chocolate [tʃakət]
I love you [jʌβu/wʌβu]
sandwich [sæ̃ɪtʃ]
pencil [pɛ̃soʊ]
quiet [kwaɪt]
tiny [tãi]
worm [wʊəm]
leg [wɛk]
finger [ɸɪŋgʊ]
look [wʊk]
spicy [paɪsi]
turn [tʃʊn/tʊn]
manger (_Fr._) [mãʒe] 'eat'
fort (_Fr._) [ɸɔχ] 'strong'
pumpkin [pʌŋkɪn]
cashew [kæʃu]
flashlight [ɸæʃ.ʔaɪt]
sword [ʃoʊt]

1;11, cont.

grand (*Fr.*)	[gʁã]	‘big’
walkie-talkie	[takitaki]	
tail	[tew]	
keep	[kip]	
square	[kweə]	
scratch	[kwætʃ]	
fall	[ɸaʊ]	
fridge	[ɸɪtʃ]	
sauter (*Fr.*)	[sote]	‘jump’
number	[nʌmʊ]	
flag	[ɸwægə]	