CLUSTER REDUCTION AND CONSTRAINTS IN ACQUISITION

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STATEMENT BY THE AUTHOR

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TABLE OF CONTENTS

TABLE OF CONTENTS - *Continued*

CHAPTER FOUR: REDUCTION OF NON-ENGLISH CLUSTERS

CHAPTER FIVE: TOWARDS A FORMAL MODEL OF PHONOLOGICAL ACQUISITION

CHAPTER SIX: CONCLUSION

TABLE OF CONTENTS - *Continued*

LIST OF FIGURES

LIST OF TABLES

LIST OF TABLES - *Continued*

ABSTRACT

This dissertation examines the phenomenon of consonant cluster reduction in young children's speech from both an experimental and a theoretical perspective. After first arguing that previous, articulatory accounts of children's cluster reductions are not satisfactory, I propose an alternative hypothesis based on Sonority Theory. Contrary to an articulatory approach which might predict that children reduce consonant clusters to whichever consonant is easier to produce, the Sonority Hypothesis predicts that children reduce clusters to whichever consonant produces the most optimal syllable. An optimal syllable is one that begins with a maximal rise in sonority from the initial consonant to the vowel and ends with a minimal (or no) sonority descent, where consonants are classified as more or less sonorous according to a Sonority Hierarchy.

This hypothesis is then tested in two experiments where subjects were asked to repeat names for imaginary animals either of the form CCVC or CVCC. In this way, cluster reductions were elicited from children ranging in age from 29-36 months old. A post-test was also conducted on each child to ensure that both consonants of any given cluster were contained in the child's consonant inventory. Results of both experiments support the Sonority Hypothesis.

Consequent to the experimental investigation, I examine several larger issues in language acquisition that are raised by this research, such as the importance of cross-linguistic and child language parallels in acquisition, and the question of variability in child

data. This discussion raises the further question of how best to account for these types of disparate properties in child language. As a means of addressing these concerns, I present one possible approach by offering a complete phonological analysis of cluster reduction in an Optimality Theoretic framework. I then examine the success of this account with respect to the issues raised earlier. In concluding this dissertation, I suggest that by also considering the effects of performance factors on children's early productions we can arrive at a fully explanatory theory of phonological acquisition that addresses all of these significant issues.

Chapter One: Prologue

"I wanna [pei] now." N, 2 year old.

1. Introduction

As children, we learn the basics of language within the first five years of life. At that time, our concern is most likely for language as a means of communication. We see language as a tool - something we need learn how to use so that we can make our way successfully through the world around us. Thus, the process we go through in acquiring language would appear to be merely a means to an end and, in itself, holds no interest for us. It is only later, as adults, that language reveals itself as an entity to be explored for its own sake. Given that language is one attribute that distinguishes us from other animals, many questions arise: precisely what is language, what comprises knowledge of language, and what is involved in the process of acquiring language? These are questions that linguists and psycholinguists have continued to study since each field's inception, and whose investigation falls into many different areas of linguistics and psychology.

For those of us interested in language acquisition, it is an unfortunate fact that the steps we took towards linguistic competency as children are not steps that we can recall as adults. Instead, we must rely on examinations of children's utterances and other behavioral data in the hopes that these will reveal what children know about language, the stages that must be traversed to achieve adult language proficiency, and ultimately, what the relationship is between child and adult language.

In pursuit of these goals, there have been numerous works undertaken on child language in areas from syntax to phonology to word learning from the perspectives of both perception and production. These works take the shape of comprehensive diary studies or longitudinal studies such as those of Leopold (1939-49), Bloom (1970), Brown (1973), and Smith (1973); shorter studies on numerous children such as that of Templin (1957); and studies examining a single phenomenon such as those of Eimas, Siqueland, Jusczyk & Vigorito (1971), and Priestly (1977). The contributions of research in child language to linguists, psychologists and others have been at least as plentiful as the number of researchers involved in the field.

Still, because child language is a relatively young field and also because of the difficulty of the research in a variety of ways, there are many areas where comprehensive research has yet to be done. One of the most fundamental and obvious questions is why children's pronunciations of words do not sound like those of adults. There are numerous examples of such differences, one of which is seen in N's production of [pei] for *play*, above. This process of reducing multi-consonant clusters to a single consonant is referred to as CLUSTER REDUCTION, and it is on this aspect of child phonology that I focus in this dissertation. I will argue that this apparently simple phenomenon can be satisfactorily understood only in the context of a theory of syllable structure and linguistic universals known as SONORITY THEORY. This claim is supported by data from two production studies conducted to test the sonority proposal against previous treatments of the phenomenon, which are based on somewhat elusive notions of articulatory ease. In addition, these data raise several issues that must be addressed in any study of child language. For example, this investigation solidifies the importance of parallels between child data and adult cross-linguistic patterns to a theory of phonological acquisition. I address this concern specifically, by modeling the resulting cluster reduction data in the constraint-based framework of OPTIMALITY THEORY (Prince & Smolensky, 1993). I show that this theory of adult linguistic behavior, inclusive of Sonority Theory, is capable of providing a unified model of both the child and the adult data with respect to the presence or absence of cluster reduction. I also examine this approach in its larger context as a theory of phonological acquisition with respect to its success or failure to respond to the other crucial issues previously raised.

Ultimately, the goals of this dissertation are to achieve a substantive, sonority-based account of cluster reduction that focuses on the similarities between child data and linguistic universals, and to argue for a relationship between child and adult language that is based on these universals. A third and more global aim is to identify properties critical to a successful theory of phonological acquisition as are brought out by this work. To this end, the present chapter provides a more detailed description of the cluster reduction phenomenon as well as a review of the earlier work on this topic. In so doing, the chapter motivates the need for an alternative analysis and, consequently, suggests the relevance of Sonority Theory as an explanation of the phenomenon. Chapter Two further details the nature of Sonority Theory and gives an explicit rendering of the proposed Sonority Hypothesis. Also in Chapter Two is a translation of the earlier accounts into one workable, contrasting hypothesis as well as a justification for the ensuing experimental research. Chapters Three and Four present the two studies that test the competing explanations, culminating in the support of the Sonority Hypothesis. Chapter Five takes stock of this research which raises issues that must be addressed by any theory of phonological acquisition. The ultimate purpose of this chapter is to provide perspective on the properties crucial to a formal model of child phonology. As one approach, the chapter offers an analysis of the cluster reduction data in an Optimality Theoretic framework, defining a specific relationship between the child and adult forms that is built on linguistic universals. Further discussion reveals the advantages and disadvantages of such a proposal when considered as a larger theory of phonological acquisition. Chapter Six concludes the dissertation with a summary of the work presented and its implications for future research.

1.1 Cluster Reduction

Many researchers have reported on children's tendencies to omit at least one of the consonants in a multi-consonant cluster (Lewis, 1936; Leopold, 1939-49; Velten, 1943; Olmsted, 1971; Smith, 1973; Ingram, 1974; Oller, Weiman, Doyle & Ross, 1976; Kiparsky & Menn, 1977; Vihman, 1979). Typical utterances for children at this stage are similar to the one mentioned earlier, such as [pun] for *spoon*, [fai] for *fly*, or [bu] for *blue*.[1] Some compr:ehensive reviews and accounts of child phonology further verify that the nature of the omission is generally predictable cross-linguistically (Locke, 1983; ?Ingram, 1989). That is, children of all languages tend to reduce the same types of clusters to the same type of consonant. For example, fricative plus stop clusters commonly reduce to the stop and not the fricative. Following this pattern are reductions like the previous [pun] for *spoon*, and also [tar] for *star* and [kai] for *sky*. Similar trends have been identified for other word-initial cluster types (Locke, 1983), as illustrated in Table 1.[2,3]

TABLE 1.1
Patterns of Cluster Reduction

Cluster Type		Reduces to:	Examples
a.	fricative+stop	stop	[ta] for *star*, [pun] for *spoon*, [kai] for *sky*
b.	stop+liquid	stop	[bu] for *blue*, [ten] for *train*, [gæs] for *glass*
c.	fricative+liquid	fricative	[fai] for *fly*, [sip] for *sleep*, [fɔg] for *frog*
d.	stop+glide	stop	[butɪfəl] for *beautiful*, [kin] for *queen*
e.	fricative+glide	fricative	[sɪŋ] for *swing*, [sɪm] for *swim*
f.	nasal+glide	nasal	[muzɪk] for *music*

The most interesting question with respect to these cluster reductions is why children consistently omit one particular consonant over another. The existence of the

[1] Square brackets indicate transcription of an utterance in the International Phonetic Alphabet (IPA).
[2] Locke (1983) does not include word-final clusters in his generalizations. Although Olmsted (1971), Ingram (1989) and others report on specific instances of final cluster reduction, there is a paucity of information on reduction patterns involving final clusters. This concern is addressed in §2.7.
[3] In these examples, the consonant that remains is identical to an original sound in the cluster; e.g., *spoon* reduces to [pun]. However, very often a child will substitute another sound of the same natural class (in this case another stop). E.g., *spoon* might reduce to [dun].

generalizations themselves speaks to the fact that the pattern of omitted consonants is not random. Children are relatively consistent in their omissions of particular consonants from clusters of the same type. Further, children do not simply omit either the first or second consonant only. Although the patterns in (b-f) in Table 1 could all be characterized as omission of the second consonant in the cluster, the pattern shown in (a) refutes this as a general hypothesis because in this case the second member of the cluster remains. Thus, children's omissions are not governed by the position of the consonant in the cluster.

Also of interest is the contrast between (a), and, (c), (e). These examples indicate that children do not simply favor certain manners of articulation of sounds, such as fricatives, because in (a) the fricative is excluded, while in (c) and (e) the fricative is retained. These examples suggest, too, that the composition of the target cluster matters in some way since the same fricatives are omitted in some clusters but not in others. For example, [s] is omitted in *spoon*, but not in *sleep*, *swing*, or *swim*.

Lastly, several groups of examples show that children do not favor certain places of articulation in the choice of consonant retained. For instance, while the reductions of [pun] for *spoon*, [bu] for *blue*, and [butɪfəl] for *beautiful* in (a), (b) and (d) might suggest a preference for the production of labial consonants ([p], [b], and [b], respectively), the reductions of [kin] for *queen*, [sɪŋ] for *swing*, and [sɪm] for *swim* refute this explanation since the labial [w] in these utterances is omitted. Similarly, for example, the production of [tar] for *star* in (a) counters an explanation based on a preference for the production of coronals, since both [s] and [t] are coronals and yet only the [s] is consistently omitted.

Also relevant are the other examples in (a) where a preference for coronals would dictate the retention of the [s] in *spoon* and *sky*, but where the [s] is, in fact, omitted; children produce [pun] and [kai], respectively.

1.1.1 Summary

Clearly, children's cluster reductions are a more complicated phenomenon than first appearances would suggest. These reductions are motivated by some very specific and intricate considerations which cannot be straightforwardly characterized as omission either by position of the consonant in the cluster or by preferential retention for certain manners or places of consonantal articulation. It is also apparent that the composition of the target cluster in some way plays a role in which consonant is omitted or retained. These facts suggest that children's cluster reductions are not just simple problem solving mechanisms but that they are responsive to an intricate array of factors, the exact nature of which will be determined in the following sections.

1.2 Previous Accounts

Unfortunately, prior accounts of the phenomenon do not satisfactorily explain the reason for children's specific reductions. Much of the initial research in child phonology focuses on the documentation, not on the explanation, of children's utterances at different developmental stages. The theme of many of these early works is children's acquisition of phonemes or phonological contrasts, most likely in response to Jakobson's (1941) view on the acquisition of the latter. Perhaps the two most extensive studies of this sort that include references to cluster reduction are Templin (1957) and Olmsted (1971), both of which have established a large descriptive store of information on the acquisition of speech sounds. While cluster reduction is certainly evident in these investigations, there are no explicit explanations given as to why children reduce clusters in certain ways, although there are precise descriptions of which consonants remain or are lost in the process.

It is probable that no analysis of cluster reduction is specifically addressed in studies such as these because of the long-held assumption that children's deviations from the adult targets are due mainly to articulatory difficulties. That is, researchers reason that children's pronunciations are different from adults because children have immature articulators. Intuitively, this view makes a lot of sense. Some things are notoriously hard to say, even for mature speakers, like the tongue twister "rubber baby buggy bumpers" or the word "sixths". For children, whose articulatory apparatus is not fully developed, pronouncing adult-like utterances from the outset may not be possible. With this as a given, early studies focused largely on descriptions of child phonological phenomena in the hopes that insight might be gained into the inherent articulatory ease of some sounds over others. By first establishing the order of acquisition of speech sounds, studies like those of Templin (1957) and Olmsted (1971) sought to discover which sounds might be intrinsically the most difficult to produce. The implication is that the first sounds children acquire are likely to be the ones that are the easiest to pronounce. For example, if [f] is acquired before [l], then [f] must be easier to pronounce than [l]. From this viewpoint, it can first be inferred that cluster reduction is children's solution to the articulatory complexity of producing two consonants in sequence, and second, that the consonant that is omitted is one that is difficult to produce. Following through on the argument that order of acquisition of consonants is equivalent to a measure of articulatory ease, one can predict that in a cluster composed of [f+l], children would omit the [l] in favor of the more easily articulated [f].[4] However, although these works do set up an invaluable criterion for assessing children's acquisition of English speech sounds, they do not provide any precise theory of articulatory ease which might explain the intricacies of children's cluster reductions. Beyond the inference that the omitted consonant is one that is difficult to pronounce, there is no measure advanced on how the complexity of speech sounds might be assessed *independently* of the phenomenon itself (but see Ann, 1993, for a theory of ease of articulation for handshapes).

A further problem with the articulatory ease approach is addressed in the work of Leopold (1939-49), who noted that his child was initially quite capable of producing consonant clusters (as in *pretty*, [prɪtɪ]), but at a later point in development reverted to reduced forms like [pɪtɪ]. In the case of regressions like these, it would be misguided to say that the child lacks the articulatory ability to produce the cluster in the later form, as correct forms are attested at an earlier stage. A similar argument against articulatory accounts is documented in Smith (1973). In giving a detailed analysis of his son Amahl's phonological development, Smith first claims that the child's underlying representations of words are commensurate with adult surface forms, and that any deviance between the

[4] This line of argument is further detailed in Chapter Two, §2.6.

child's own pronunciations and that of the adult is due to incomplete mastery of the articulators. For example, a child pronouncing *blue* as [bu] would have an underlying lexical representation similar to /blu/. The child, therefore, knows what the target word is, so any subsequent mispronunciations are the result of articulation difficulties. In some cases, however, Smith notes that a sound his son omits in one particular place (and thus might be considered "articulatorily difficult"), is produced in the same position in some other word but as the realization of a different sound. As he states: "...*puddle* was pronounced [pʌgəl] whilst *puzzle* was pronounced [pʌdəl]." (Smith, 1973:159; but see Macken, 1980). Clearly, the child's failure to correctly pronounce [d] in *puddle* was not the result of any articulatory incapabilities since the [d] is correctly produced in the child's version of *puzzle*. Data like these do not necessarily discount articulatory explanations of child phonology, but they do suggest that measures of articulatory ease need to be much more precise, since it is not always the case that sounds omitted in one instance are unequivocally more difficult. With respect to cluster reduction, this is already known to be true, since an example similar to the puzzle-puddle-"puggle" phenomenon was identified in §1.1. Table 1.1 showed that while [s] was omitted in *star*, *sky* and *spoon*([tar], [kai], and [pun]), it was produced in *sleep*, *swim*, and *swing* ([sip], [sɪŋ], and [sɪm]). It might be suggested on the basis of the first three examples that word-initial [s] is articulatorily difficult and so is omitted, but this cannot be maintained since the last three examples show the production of [s] in this very position.

Smith's own explanation for the puzzle-puddle-"puggle" enigma, and the real focus of his work, was that children utilize a set of ordered "realization rules" (i.e. phonological rules) which specify the form of their surface pronunciations. These rules apply in precise environments to the child's underlying lexical representations. In the case of puzzle-puddle-"puggle", a rule velarizing alveolar stops before [l] turns *puddle* into "puggle", while a *later* more general rule changes the fricative [z] to [d] in *puzzle* to produce *puddle*. Table 1.2 gives a simplified illustration of how these rules affect the various transformations.

TABLE 1.2
The Puzzle-Puddle-"Puggle" Explanation

Child's Underlying Representation:	**/pʌdəl/**	**/pʌzəl/**
Rule (n): /d/ → /g/ __ l	/pʌgəl/	does not apply
Rule (n+1): /z/ → /d/	does not apply	/pʌdəl/
Child's Pronunciation:	[pʌgəl]	[pʌdəl]

On this view, children's pronunciations result functionally from processes aimed at achieving articulatory ease and formally from a set of ordered phonological rules, in which these processes are encoded. One consequence of the ordering of rules is that rules applying later are not subject to those applying earlier. Thus, the output of *puzzle* via Rule (n+1) does not ultimately become "puggle", because underlying /pʌzəl/ has already passed by the rule affecting this transformation (Rule (n)). A final, more relevant consequence of these rules is that they sometimes apply irrespective of the child's articulatory capabilities.

This emphasis on ordered, rule-based explanations of child phonology appears in many other works (e.g. Stampe, 1969; Ingram, 1974; Kiparsky & Menn, 1977; Menn, 1978). However, it is not clear that phonological rules in general can be translated into a precise account of the cluster reduction phenomenon. On this view, cluster reduction results from the application of phonological rules. These rules can be variously characterized as specific instantiations (e.g., [bl]→[b]) or as representing general patterns (e.g., SL→ S, where S is a stop consonant and L is a liquid consonant). But as Ingram (1974) intimates, rules of either sort are "statement rules" and as such are limited to descriptive adequacy and do not have explanatory adequacy (p.61). In themselves, rules merely describe which consonant is omitted in the case of cluster reduction, but they do not explain the choice of the omitted consonant. In fact, children's motivation for the application of these rules is still assumed to result from the inherent articulatory complexity of certain sounds or sequences of sounds. For example, Menn (1978) suggests that cluster reduction is one of several processes aimed at satisfying a general constraint that bans the production of sequences of consonants. As she states: "these constraints are interpretable as manifestations of the young child's limited ability to plan and execute complex motor activity." (p.164). Thus, while the use of phonological rules has allowed for the conjoining of children's early speech phenomena under a single phonological system, there still remains the underlying assumption that articulatory ease is responsible for children's mispronunciations in general.

Unfortunately, in these works and elsewhere there has been no concomitant advance towards an independently motivated and detailed theory of articulatory ease. While there have been many efforts to provide such a theory including research outside the field of language acquisition (e.g. Ohala, 1974; Lindblom, 1983; Westbury & Keating, 1986) satisfactory definitions of articulatory ease or complexity remain intangible. This means that with respect to cluster reduction there is still only the intuitive but ill-defined notion that the choice of omitted consonant is governed by articulatory considerations.

1.2.1 Summary

Overall, previous investigations of cluster reduction can be seen to establish the existence of the phenomenon itself in conjunction with some detailed descriptions of the process. From these studies, researchers have extracted certain patterns of reduction which speak to the uniform nature of the phenomenon, as was shown in §1.1. The underlying explanation of these reductions is assumed to be articulatory in nature but there are some evident inadequacies in such an approach.

The most pressing is the lack of a specific theory of articulatory ease. The closest approximation with respect to cluster reduction is that the consonant that is omitted is the one that is most difficult to pronounce, but this suffers from at least two faults. One is the point first brought up in Smith's (1973) work that consonants omitted in one instance should not automatically be assumed to be unpronounceable. The other fault is that there is a potential for circularity in this measure of ease, since the question could easily be posed in the reverse: either the consonant that is omitted tell us which one is the most difficult to pronounce, or the consonant that is most difficult to pronounce tells us which one is to be omitted. What is clearly needed is an explanation of cluster reduction that can be motivated exclusive of the phenomenon itself. In the sense that none of the previous accounts achieve this independence, it can be said that no satisfactory explanation of the cluster reduction facts has been accomplished to date.

1.3 The Alternative Theoretical Source

To help identify the necessary aspects of a precise theory of cluster reduction, it would seem beneficial to review the knowledge that has been gained from previous discussion. First, it was shown in §1.1 that a theory of cluster reduction cannot rely solely on any of three factors: position of the consonant in the cluster, any specific preferences for manners of consonant articulation, or any specific preferences for places of consonant articulation. Each of these possibilities was examined and dismissed. With respect to position, it was shown that sometimes children omit the first consonant in a cluster, and other times children omit the second consonant. With respect to manners of consonant articulation, it was shown that no particular preferences could be maintained (e.g. a preference for the production of fricatives) since in some cases consonants with the same manner of articulation were at one time omitted and at another time retained. A similar argument was made for the dismissal of place of consonantal articulation (e.g. a preference for labials or coronals) as a factor in cluster reduction. An additional element revealed to be of importance in this section was the fact that the composition of the target cluster appears to play a role in determining the consonant that is deleted. This is true because the same consonant is sometimes omitted in one cluster (e.g. the [s] in [st]) but retained in another (e.g. the [s] in [sl] or [sw]). This suggests that whether or not a consonant is omitted depends in part on the other consonant it is paired with in the cluster.

From this, a theory is indicated that allows for a different classification of consonants. This classification should, at the very least, be capable of characteristically defining a relationship *between* two consonants in a cluster, and ideally should also be capable of defining properties of consonants in isolation. The correct theory cannot solely be responsible to the latter (i.e. definitions of consonants in isolation) because manner and place of articulation are already capable of doing this and both of these characterizations fail to account for cluster reduction. In addition, the correct theory must assess a more substantive relationship between consonants than relative position in a cluster, because this type of assessment has also already been discounted. Furthermore, as was made evident from §1.2, an accurate theory of cluster reduction must also have explanatory power. The theory should be independently motivated in a domain outside of the cluster reduction phenomenon.

There is, in fact, one theory that meets all of these qualifications and that is Sonority Theory (Jespersen, 1904; Hooper, 1976; Steriade, 1982; Clements & Keyser, 1983; Selkirk, 1984; Clements, 1990). This linguistic theory of syllable structure was originally proposed to explain the cross-linguistic preference for syllables of certain shapes. Thus, this theory can certainly claim explanatory power as it is independently motivated by phenomena other than cluster reduction. Also, in achieving an explanation of cross-linguistic syllable patterns, Sonority Theory provides a classification of consonants (and vowels) with respect to their relative loudness (also referred to as *sonority*) as well as a general ranking of sounds with respect to each other. These properties are just what is required from a theory of cluster reduction, as established previously.

In the following chapter, I detail the theoretical underpinnings of Sonority Theory and solidify its relevance to the cluster reduction phenomena. I then propose the Sonority Hypothesis which makes specific predictions about the cluster reduction data and which is ultimately shown to be the correct account of this phenomenon in children's early speech.

CHAPTER TWO: THE HYPOTHESES

" Cause I have a petty dess." M, 2 year old.

2. Introduction

The primary goals of this chapter are to provide a more comprehensive discussion of Sonority Theory and to detail a specific Sonority Hypothesis for application to the cluster reduction phenomenon. This discussion first reviews the empirical facts already accounted for by Sonority Theory and defines the concept of sonority. In addition, relevant facts about English syllable structure are presented both as a means for understanding a theory of sonority as well as a means for advancing the Sonority Hypothesis. It will become apparent that English is a language especially suited for testing a sonority-based theory of cluster reduction. However, in order to place this alternative proposal in context with the previous work, a secondary goal of this chapter is the formulation of a possible contrasting hypothesis based on articulatory ease. This latter hypothesis utilizes definitions previously acknowledged as unsatisfactory but attempts to build a reasonable, working alternative to the sonority-driven explanation. Finally, I explain the necessity for an experimental investigation of the phenomenon by referring back to the observations made by previous researchers (shown in §1.1) and pointing out their inadequacy for distinguishing between the competing hypotheses.

2.1 Empirical Basis of Sonority

Surveys of languages, most notably those of Greenberg (1978), reveal that certain syllable shapes are generally preferred over others cross-linguistically. For example, consonant-vowel (CV) syllables predominate in most languages, while syllables with more complex structure (e.g. CVC, CCVC, CVCC, CCVCC) are found increasingly rarely across languages. Additionally, it is true that languages that tolerate more complex syllables also accommodate the simpler syllable shapes embedded in the larger structure, maintaining a subset relationship (D. Ohala, 1992; Fikkert, 1994). For example, a language that contains CCVC syllables will also contain CV, CCV, and CVC syllables. Thus, there are no languages which display only the more elaborate syllable shapes to the exclusion of the most basic and preferred syllable shape, CV. Table 2.1 further clarifies these delineations.

TABLE 2.1
Syllable Structure Relationships

A. CV syllables:	common to all languages
B. CVC, CCV, CCVC syllables:	less common
C. CCCVCCC syllables:	extremely rare
If a language has C then B; if B then A	

Rudimentary facts like these are enhanced by more detailed observations about orderings of the individual segments found within syllables: certain orderings are commonly found in languages, while other orderings are rare or nonexistent. In English, for example, there are many words that begin with the sequence *pl* (*play, plow, platypus*). However, there are no words beginning with the sequence *lp* (**lpay, *lpow, *lpatypus*). Indeed, sequences of sounds such as *pla*, *tra*, *art*, and *alp* are more commonly found in languages than *lpa*, *rta*, *atr*, and *apl* (Sievers, 1881; Jespersen, 1904; Saussure, 1916; Grammont, 1933). A surfeit of data like these led researchers to propose that the "sonority" of an individual sound affects its propensity to combine freely with other sounds in a syllable, where sonority can be defined as a sound's "...loudness relative to that of other sounds with the same length, stress, and pitch" (Ladefoged, 1975:221). By this definition, vowels are the most sonorous elements in a syllable while consonants can be broadly ranked such that glides (*w,y*) are nearest in sonority to vowels, then liquids (*l,r*), then nasals (*m,n*), then fricatives (*s,f,v,z*) and lastly, stops (*p,b,t,d,k,g*). Figure 2.1 gives an arrangement of sounds along these lines into a Sonority Hierarchy (Jespersen, 1904; Steriade, 1982; Clements, 1990). Sounds leftmost on the scale are the least sonorous (i.e., stops) while those on the right are the most sonorous (i.e., vowels).

Stops	<	**Fricatives**	<	**Nasals**	<	**Liquids**	<	**Glides**	<	**Vowels**
[t,d]	<	[s,f]	<	[m,n]	<	[l,r]	<	[w,y]	<	[a,i]

Figure 2.1. The Sonority Hierarchy.[1]

[1] Finer-grained sonority scales, such as Jespersen's (1904), propose further distinctions among vowels, voiced and voiceless stops, fricatives, and liquids. However, not all researchers agree on these distinctions nor on the appropriate rankings in such a close analysis. The sonority scale presented in Figure 2.1 is one with which most researchers would agree and is most appropriate to the current study.

Given a hierarchy like this one, an explanation of why some sequences of sounds are preferred over others is quite straightforward: between any element in the syllable margin and the vowel, only sounds that are higher in sonority are permitted. This principle is generally known as the Sonority Sequencing Principle (SSP) and has been characterized in various guises by Hooper (1976), Kiparsky (1979), Steriade (1982), and Selkirk (1984), among others. Thus, sequences like *pla*, *tra*, *art*, and *alp* are preferred because the ordering of the individual segments conforms to the SSP: all members of the syllable from the outermost consonant to the vowel are successively higher in sonority (cf. Figure 2.1). In contrast, sequences like *lpa*, *rta*, *atr*, and *apl* are dispreferred because sounds lower in sonority are flanked by sounds higher in sonority. Such syllables do not conform to the SSP. According to the SSP, sounds between the vowel (or sonority peak) and the margins of a syllable should be successively lower in sonority, with sounds of least sonority on the outermost edge of the syllable. Clearly, a sequence like *lpa* violates this notion, as *l* is on the edge of the syllable but is higher in sonority than *p*. Figure 2.2 illustrates the preferred sonority sequencing of *alp* versus the dispreferred string *apl*.

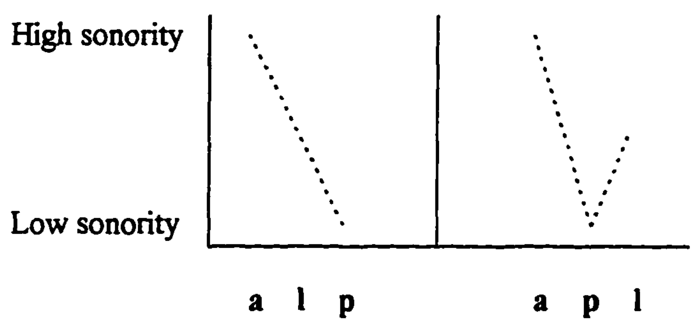

Figure 2.2. Sonority sequencing in *alp* vs. *apl*.

The Sonority Hierarchy and the SSP can fully account for the preferred consonant sequences in languages as described by Sievers (1881) and others. However, these notions cannot also independently account for Greenberg's (1978) observation that the CV syllable is the most preferred syllable shape cross-linguistically. Other aspects of sonority (to be discussed below) will account for this fact.

2.2 The Sonority Cycle and the Optimal Syllable

Clements (1990) observes that a delineation of sounds along a sonority scale makes it possible to characterize syllables in terms of a rise and fall in sonority. All vowels are sonority peaks in a syllable, with consonants on each side of the vowel either affecting a rise in sonority (on the left margin) or a fall in sonority (on the right margin). In his words, "[s]equences of syllables display a quasiperiodic rise and fall in sonority, each repeating portion of which may be termed a *sonority cycle*" (Clements, 1990:299). Such a cycle is easily made apparent by graphically overlaying a series of syllables with a contour line, as in Figure 2.3.

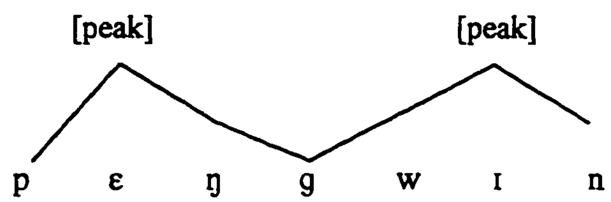

Figure 2.3. The sonority contour on the word *penguin* [pɛŋgwɪn].

As the contour line indicates, each syllable is defined by a sonority peak, the vowel, and is delineated by a rise and fall in sonority on either side of the peak. In the word *penguin* [pɛŋgwɪn], there are clearly two sonority cycles (or two syllables). The first cycle begins with a sharp rise in sonority from the *p* to the *ɛ*, following which there is a gradual fall in sonority to the *ŋ* and the *g*. Then sonority rises again to the *w*, peaking at the *ɪ*, and falling to a midpoint at the *n* (the lowest points in the two cycles being the *p* and the *g*).

Using the notion of the sonority cycle, Clements further outlines a definition for an optimal syllable. He notes that syllables prefer a particular sonority contour that is characterized by a maximal rise in sonority at the beginning and a minimal, or no, sonority descent. This defines the optimal syllable shape, CV, which has already been described as the most preferred syllable shape cross-linguistically. Furthermore, the preferred identity of the initial C in such a syllable is a stop, since this class of consonant provides the sharpest rise in sonority from the consonant to the vowel. Thus, a syllable like *ta* is preferred to a syllable like *sa* or *na*. Thus, the ideal pattern of sequences of syllables is similar to the graphic shown in Figure 2.4, where S = stop and V = vowel.

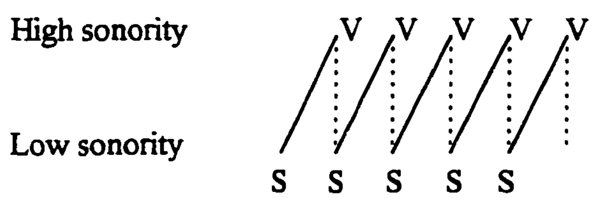

Figure 2.4. The ideal sonority cycle.

A further important claim is that in syllables that do contain a final consonant (CVC), a right margin of high sonority like the [n] in *tan* is preferred to one with low sonority, like the [s] in *tas* or the [t] in *tat*.

As these claims are critical to the later formulation of the Sonority Hypothesis, it is important to substantiate their validity. In fact, there is language internal evidence from reduplication in Sanskrit that supports Clement's notion of an optimal syllable. In Sanskrit, one form of reduplication involves prefixing a monosyllabic reduplicant to the verb stem and is used to imply repetitive or intensive action (Steriade, 1988). Figure 2.5 gives some examples of this phenomenon. All data is taken from Steriade (1988) and in keeping with that work, only intermediate forms are cited to abstract away from other irrelevant processes. In the figure below, long vowels are indicated with a following colon (V:) and retroflex consonants are indicated by a subscripted dot (Ç).

	Root	Intensive Form (Full Grade)	Gloss
a.	vais/viṣ	vai-vaiṣ-	'be active'
b.	pat/pt	pa:-pat-	'fly, fall'
c.	grabh/gṛbh	ga:-grabh-	'seize'
d.	vyadh/vidh	va:-vyadh-	'pierce'
e.	stan	tan-stan-	'thunder'
f.	skand/skṇd	kan-i-skand-	'leap'
g.	mard/mṛd	mar-mard	'rub, crush'
h.	dhvans/dhvṇs	dhan-i-dhvans	'sound'

Figure 2.5. Examples of Sanskrit intensive reduplication.

There are several important points to note in these data which together argue that the reduplicating prefix is formed by making the most optimal CVC or CVV syllable from the verb root. First, the contrast between the forms in (a), (b), and (c), (d), reveal that the reduplicant must contain only a single onset consonant. Although the verb stems in (c) and (d) contain consonant clusters, only a single consonant appears in the prefix. Second, the forms in (c), (d) can be compared to those in (e), (f) to show that the formation of the reduplicant cannot be analyzed as reduction to either the first consonant or the second consonant, since both types of reductions occur. In fact, the consonant that remains in all four cases (c-f) is the least sonorous consonant in the onset cluster. For example, in (d) the root *vyadh/vidh* reduplicates as *va:-vyadh*, where the initial consonant cluster [vy] reduces to the least sonorous of the two consonants, [v]. In (e) the root *stan* reduplicates as *tan-stan*, where the initial consonant cluster [st] reduces to the least sonorous of the two consonants, [t]. The reduplicant is thus formed by creating the most optimal onset to the syllable (i.e, the consonant that remains is the one that provides a maximal rise in sonority given the composition of the cluster in the stem). The last two examples in (g), (h) show that root-final consonant clusters also reduce in the reduplicant. However, these clusters reduce to the consonant that is most sonorous, as would be predicted if the resulting monosyllabic prefix is to be most optimal. For example, in (g) the stem *mard/mr̥d* reduplicates as *mar-mard*, where the final cluster [rd] reduces to the most sonorous of the two consonants, [r]. Lastly, it is important to note that both clusters in the verb root in (h) reduce so as to make the most optimal reduplicant: a monosyllabic prefix with the most maximal rise in sonority at the beginning of the syllable and a minimal sonority descent. Thus, the reduplicant formed from the root *dhvans/dhvṇs* is *dhan*; the cluster [dhv] is reduced to the least sonorous consonant [dh] and the cluster [ns] is reduced to the most sonorous consonant [n]. Arguments similar to the above can also be made for other types of Sanskrit reduplication (see Gnanadesikan, 1995) and further substantiate Clements' notion of an optimal syllable.

Thus, the preference for CV syllables (specifically, the optimal stop-vowel syllable), as well as the preference for certain sound patterns in syllables over others across languages, can all be explained by making reference to the Sonority Hierarchy, the SSP, and the sonority cycle.[2] It should be evident that, in general, the more syllables diverge from this optimal syllable, the more complex such syllables become, and the more rarely they are found in languages. However, it is a fact that some languages do allow extremely complex syllables, to the extent that exceptions to the SSP and the sonority cycle are found. Thus, these principles cannot be considered truisms, but are rather seen to characterize how syllables are customarily organized.

2.2.1 A Proviso

The next step in this review is to look to the English language to see how the concept of sonority defines the arrangement of most syllables found in this language, as

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[2] Current phonological theory embraces this notion of optimality in a formal, constraint-based framework referred to as Optimality Theory. Clement's notion of optimal syllable is easily incorporated into just such a framework. A detailed discussion of the integration of these two concepts is presented in Chapter Five.

well as to provide examples of exceptions to the SSP. However, before embarking on this task, it is important to add a proviso, which is that the definition of sonority is not quite so unfettered as was previously implied. Ladefoged's (1975) definition offers no exact means by which loudness may be measured except as compared to other sounds. Indeed, despite the intuition by some researchers that sonority should be defined by phonetic parameters, either acoustic (Keating, 1983; Lindblom, 1983) or articulatory (Price, 1980), others point out that there is as yet no method for measuring sonority which has been generally accepted (Ohala & Kawasaki, 1984), while still others propose abandoning sonority altogether (J. Ohala, 1992). Equally engaged in the debate are those who propose that sonority should be defined in terms of distinctive features (Basbøll, 1977; Clements, 1990; Hooper, 1976; Lekach, 1979; Selkirk, 1984; Steriade, 1982; among others). Similar to those in the phonetic encampment, there is as much internal debate among the proponents of feature theory as there is external debate between the two factions.

Nevertheless, it is clear that sonority (or some other conglomeration of parameters for which sonority can be seen as a cover term) is a concept that syllables across all languages generally respect. It is sonority's ability to characterize the organization of preferred syllables that has been the focus of the current section, leaving the issue of an agreed-upon definition of the concept to other researchers. It is this first aspect of sonority which will provide the basis for a theory of cluster reduction, a better understanding of which will be gained by a brief description of English syllables.

2.3 Sonority in English

It was noted earlier that the English language lacks sequences of consonants like *lp-* at the beginning of syllables. This fact was shown to result from a constraint on sonority sequencing (the SSP) that disallows segments low in sonority to be flanked by sounds higher in sonority. Similar observations can be made regarding the lack of other initial sequences in the language, such as *rt-*, *rg-*, and *lk-*. The absence of sequences like these can be attributed to the fact that nearly all initial syllable sequences (or onsets) in the language obey the SSP. This is also true of syllable final sequences (or codas). Thus, *-lp*, *-rt*, *-rg*, and *-lk* would be perfectly fine codas in English, whereas *-pl*, *-tr*, *-gr*, and *-kl* (which are fine as onsets) are not legal codas. The dichotomous behavior of sequences of sounds like these reflect the adherence of English syllables to the SSP and to the notion of the sonority cycle. Consider the monosyllabic English words *plug* [plʌg] and *gulp* [gʌlp], shown with sonority contours in Figures 2.6a and 2.6c. The same two consonants are juxtaposed differently in order to form legitimate initial and final clusters. The sequence *pl-* is allowed as an onset (but would form an illegal coda, 2.6b) because sonority rises from the *p* to the *l*. Conversely, the sequence *-lp* is permitted as a coda (but not as an onset, 2.6d) because sonority falls from the *l* to the *p*.

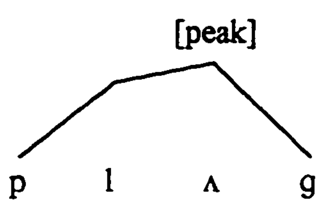

Figure 2.6a. The sonority contour on the English syllable *plug*.

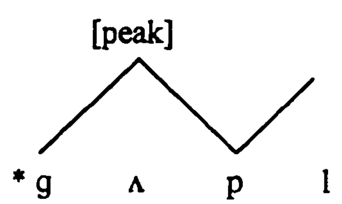

Figure 2.6b. The sonority contour on the non-syllable *gupl* [gʌpl].

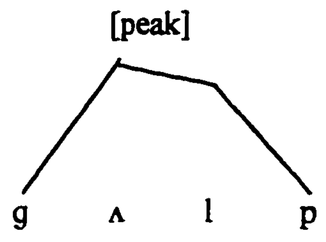

Figure 2.6c. The sonority contour on the English syllable *gulp.*

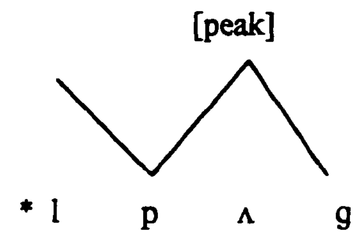

Figure 2.6d. The sonority contour on the non-syllable *lpug* [lpʌg].

These observations might lead to the proposal that any two consonants may combine freely into an onset or a coda in English provided the ordering of the two consonants adheres to the SSP and the sonority cycle. However, the actual set of possible English onsets and codas is much smaller than the set of all clusters that conform to the SSP (Borowsky, 1986; Clements & Keyser, 1983; Selkirk, 1982). As Table 2.2 shows, there are many of these gaps (indicated by a "-") in the cluster inventory of English. With the exception of three clusters to be discussed later, Table 2.2 lists all the occuring two-consonant clusters in English (N = nasal consonant).[3]

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[3] To be more accurate, the table represents two-consonant clusters occuring in monosyllabic words in English. A different characterization would be necessary for clusters occuring medially in polysyllabic English words. The introduction of tri-consonantal onset clusters (such as the onset *str* in *street*, or the coda *rnt* in *burnt*) would also expand this characterization, as would more complicated structures like the coda in *sixth* [sɪksθ]. However, the data in Table 2.2 comprise the set most appropriate to this dissertation because all items used in later experiments are monosyllabic and contain only two-consonant clusters.

TABLE 2.2
English Consonant Clusters

	Onsets				Codas			
	Cl	*Cr*	*Cw*	*CN*	*rC*	*lC*	*NC*	*sC*
p	pl	pr	-	-	rp	lp	Np	sp
b	bl	br	-	-	rb	lb	-	-
t	-	tr	tw	-	rt	lt	Nt	st
d	-	dr	dw	-	rd	ld	Nd	-
k	kl	kr	kw	-	rk	lk	Nk	sk
g	gl	gr	gw	-	rg	lg	Ng	-
θ	-	θr	θw	-	rθ	lθ	Nθ	-
f	fl	fr	-	-	rf	lf	-	-
v	-	-	-	-	rv	lv	-	-
s	sl	-	sw	sN	rs	ls	Ns	-
š	-	šr	-	-	rš	lš	-	-
z	-	-	-	-	rz	lz	nz	-
N	-	-	-	-	rN	lN	-	-
č	-	-	-	-	rč	lč	nč	-
ǰ	-	-	-	-	rǰ	lǰ	nǰ	-

Clearly, other restrictions (or filters, cf. Clements & Keyser, 1983) must hold in the language in order to rule out those clusters which do not occur but nevertheless abide by the SSP. For example, the lack of an initial *pw-* cluster in English cannot be explained by making recourse to sonority sequencing. Any initial stop-glide cluster such as this one adheres to the SSP. The absence of this cluster is explained by making reference to a language specific filter which rules out the occurrence of two adjacent labial consonants. Consequently, while *tw-*, *dw-*, *kw-* and *gw-* are possible onset clusters in English, *bw-* and *pw-* are not because contiguous labials are disallowed. A similar filter is one that rules out the occurrence of adjacent coronal consonants. This eliminates the onsets *tl-* and *dl-* while still allowing *pl-*, *bl-*, *kl-*, and *gl-*. Other languages may or may not have such filters or may have different ones. In any case, filters like these and other similar notions are suggested as explanations for gaps of the type in Table 2.2 (Borowsky, 1986; Clements & Keyser, 1983; Selkirk, 1982). Thus, while all consonant clusters in the table can be accounted for by the SSP, it is not the case that all clusters abiding by this principle occur in a language.

Furthermore, a very small number of exceptions to sonority sequencing do occur in English that were not listed in the table. The initial clusters *sp-*, *st-*, and *sk-* are also possible in this language despite the fact that they disobey the SSP. In order to maintain an optimal sonority contour, the segments lowest in sonority (the stops *p-t-k*), should be on the left edge of the cluster, but in these cases the fricative [s], although higher in sonority, is closest to the left margin. Such a juxtaposition of segments in a cluster is referred to as a "sonority reversal". Clusters with similar properties can also be found in other languages (for example, the onset *mx-* in Russian, or the coda *-tr* in French). Generally, these exceptions are treated by assigning the offending segment(s) a unique structural position either inside or outside the syllable. In the first case, as argued by Selkirk (1982), an [s]-stop cluster such as *sp-* is considered to function like a single obstruent and is assigned to a position in an auxiliary template within the syllable, as shown in Figure 2.7 for the word *split* [splɪt].[4]

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[4] It should be noted that the representations given are deliberately simple and are not intended to support any particular syllable internal structure. More elaborate structure is not necessary for the current work.

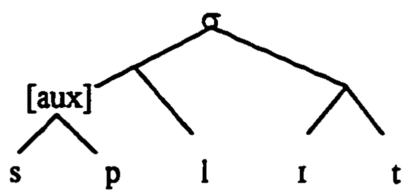

Figure 2.7. A representation of the word *split* á là Selkirk.

In the second case, as argued by Borowsky (1986), the offending [s] is assigned a position outside the syllable where it is adjoined at the word level. Compare the syllabic representation of the word *snore* [snɔr] in English with that of the word store [stɔr] in Figures 2.8a and 2.8b. In (2.8a), the initial consonant cluster adheres to the SSP and in (2.8b), the initial consonant cluster violates the SSP.

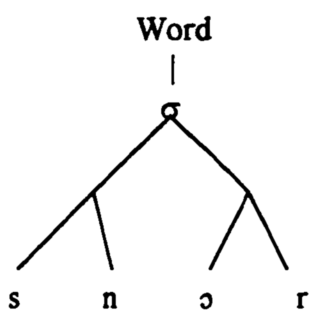

Figure 2.8a. The English word *snore.*

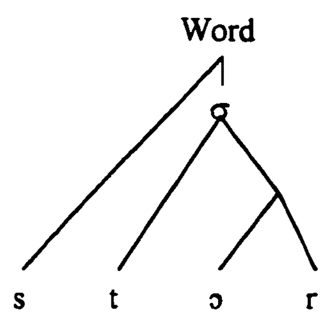

Figure 2.8b. The English word *store.*

Regardless of which account is most effective in explaining the nature of initial [s]-clusters in English (and there are numerous arguments for and against each one), it is clear that as exceptions to sonority sequencing, these clusters (by their very rarity cross-linguistically) require special attention. It is important to emphasize that exceptions to the principle of sonority sequencing occur only in a minor percentage of languages. Therefore, it is accurate to say that the SSP is a prescript that almost all syllables in languages obey. As has been shown with English, sonority sequencing accounts for many of the occurring clusters in languages and rules out many of those that do not occur. Further restrictions or caveats may be necessary to completely describe a language's cluster inventory, but much work is done by making reference to the SSP alone. The present proposal is that sonority's usefulness is not restricted to an account of only these sorts of facts. Aspects of sonority theory are also readily applied to the phenomenon of cluster reduction in child language.

2.4 The Sonority Hypothesis

The ensuing Sonority Hypothesis is meant to give substance to the notion that children's early productions are simplifications of models in the adult language. As was discussed in Chapter One, this claim has generally lacked discrete parameters for measuring the optimality of one utterance as compared to the next. I propose that sonority provides such measures, and suggest that when children reduce clusters, they are doing so in an effort to produce the most optimal syllable as defined by the sonority cycle. Per the earlier definition, an optimal syllable is characterized by a maximal rise in sonority at its beginning and a minimal, or no, sonority descent at its end. When a child produces, for example, *pay* [pei] for *play* [plei], she does so because adherence to the sonority cycle demands the reduction to *pay* [pei] and not *lay* [lei] or *ay* [ei] because *pay* provides a sharper rise in sonority in the onset than does *lay* or *ay*.

Overall, this Sonority Hypothesis (SH) makes two basic claims. These are listed in Table 2.3.

TABLE 2.3
The Sonority Hypothesis

H1:	Initial clusters reduce to whichever consonant creates a maximal sonority rise. (See examples a-e in Table 2.4)
H2:	Final clusters reduce to whichever consonant creates a minimal sonority descent. (See examples f-k in Table 2.4)

This delineation echoes the general claim of the SH, which is that children reduce clusters in such a way that the resulting syllable exhibits the most optimal sonority contour. Table 2.4 shows how the SH would apply to some of the clusters of English (from Table 2.2) now collapsed by type of cluster.

TABLE 2.4
The Sonority Hypothesis and English Clusters

	Onsets	**Example**	**Predicted Reduction**
a.	stop-liquid	*pl-*	stop (*p*)
b.	stop-glide	*tw-*	stop (*t*)
c.	fricative-liquid	*fr-*	fricative (*f*)
d.	fricative-glide	*sw-*	fricative (*s*)
e.	fricative-nasal	*sn-*	fricative (*s*)
	Codas	**Example**	**Predicted Reduction**
f.	liquid-stop	*-lp*	liquid (*l*)
g.	liquid-fricative	*-rf*	liquid (*r*)
h.	liquid-nasal	*-rn*	liquid (*r*)
i.	nasal-stop	*-mp*	nasal (*m*)
j.	nasal-fricative	*-ns*	nasal (*n*)
k.	fricative-stop	*-st*	fricative (*s*)

For the onsets, the SH predicts a reduction that creates a maximal rise in sonority from the consonant to the vowel. In the clusters (a-b), this is the stop and (c-e), the fricative. For the codas, the SH predicts a reduction that creates a minimal descent in sonority from the vowel to the consonant. In (f-h), this is the liquid, in (i-j), the nasal, and in (k), the fricative.

Additionally, there is a more intricate claim of this approach not brought out in the table. The SH predicts that the same cluster should reduce differently depending on whether it is initial or final. Ordinarily, it would be difficult to test such a claim given that the majority of the occurring clusters in languages obey sonority sequencing (like those in Table 2.4). This means that a cluster like *-lp*, which is a legitmate coda in English, cannot (and does not) also occur as an onset because as an onset it disobeys the SSP. However, because English contains some clusters with sonority reversals (e.g. the onsets *sp-*, *st-*, and *sk-*), the claim that the same cluster should exhibit differential behavior is testable. These clusters can be both onsets and codas. For example, an initial [sk-] cluster as in *sky* [skai] should reduce to [k] and not [s] because stops are less sonorous than fricatives and will provide a sharper sonority rise. See Figure 2.9 below (an asterisk indicates a non-optimal reduction).

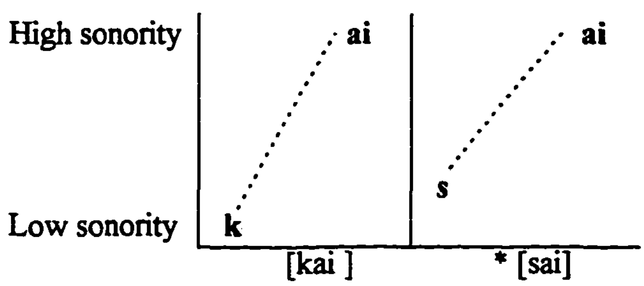

Figure 2.9. Sonority contours on [kai] vs. [sai] as reductions of *sky* [skai].

However, a final [-sk] cluster as in *musk* [mʌsk] should reduce to [s] and not [k] because fricatives are more sonorous than stops and will provide a minimal sonority descent. See Figure 2.10 below.

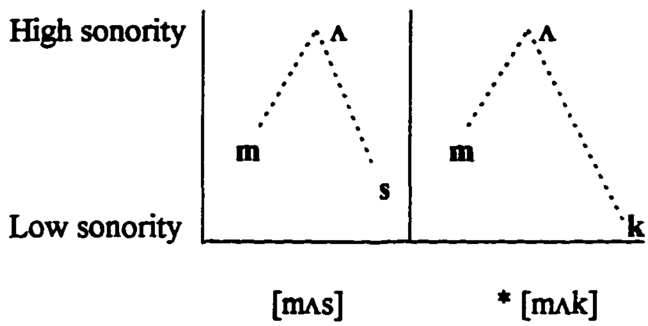

Figure 2.10. Sonority contours on [mʌs] vs. [mʌk] as reductions of *musk* [mʌsk].

Thus, the Sonority Hypothesis makes several specific predictions about the particular reductions that one should expect to find in young children's speech. These predictions are based on notions of preferred sonority contours in syllables which provide one metric for measuring the optimality of an utterance.

2.5 Summary of Sonority and the Sonority Hypothesis

In the first half of the chapter, I have presented one possible account of children's cluster reductions. This proposal relies on various aspects of sonority theory to explain the shape of children's productions in the same manner that sonority can explain the general organization of syllables across languages. In this way, the two phenomena are linked by a notion of universality, such that syllable shapes that are most preferred in languages are those that are seen in children's early productions. The Sonority Hypothesis specifically utilizes the notion of an optimal syllable to predict the particular shape of children's reductions. If such predictions are found to be true, the reason children prefer certain reductions over others is finally made explicit: when children reduce clusters, they produce the most optimal production as defined by the sonority cycle.

What now remains is to test the predictions of this sonority-based theory, but such a test is most meaningful if another account is available for contrast. Even if preliminary observations of trends in cluster reduction, like those reported in Ingram (1989) and Locke (1983), supported all of the claims of the SH, this would not be conclusive because another account might be equally capable of supporting the data. Most likely to compete with the SH is an account based on the notion of articulatory ease. While it has been discussed in Chapter One that no such account has ever been explicitly rendered, the second half of this chapter details one possible version of a theory of cluster reduction based on ease of articulation. This alternative hypothesis provides a competing account to the Sonority Hypothesis and any test of the theory is then more rigid. This thesis proposes to test these contending explanations in a series of two experiments. Accordingly, a short discussion of the need for these investigations is also provided in the succeeding half of the chapter.

2.6 Articulatory Ease

As already indicated in Chapter One, early studies of child speech tacitly assumed that young children's mispronunciations of adult forms reflected the immaturity of their articulators (e.g., Locke, 1983; Menn, 1983; Oller and MacNeilage, 1983). Thus, children's reduced forms were supposed to arise from constraints on their motor capabilities but without (as has been mentioned previously) explicit explanations as to the nature of these limitations. However, as a result of this assumption, a link was logically presumed to exist between those sounds first appearing in children's utterances and their associated ease of articulation. Given that some sounds are intrinsically more difficult to pronounce than others (involving a more complicated series of articulatory gestures, perhaps), it was thought conceivable that sounds appearing early in a child's inventory are those which are capable of being produced with some degree of articulatory ease. This notion is bolstered by the fact that cross-linguistically children tend initially to produce the same types of sounds (Locke, 1983).

Pushing this concept further provides a measure of complexity of speech sounds: sounds that are easiest to pronounce are those that children acquire first. Consequently, the order of acquisition of consonants shown in Figure 2.11 can be considered by implication to be the ranking of these consonants with respect to articulatory ease (where difficulty increases left-to-right). [5]

[5] It is important to note that these data were collected from a large sample of children (147), ranging in age from 2-4 years old. Thus, Figure 2.11 shows a general developmental pattern and mediates some of the variability found in children's acquisition of speech sounds.

n > m p h f w ŋ > t k b g s > y d > l r > š č ǰ > v > z ž > θ ð

Figure 2.11. A ranking of the ease of speech sounds (adapted from Locke, 1983:73).

On this view, [n] is pronounced with the most ease and sounds then increase in difficulty rightwards with [θ] and [ð] being the most complicated.

Granted this argument is somewhat circular, but the circularity is circumvented to a degree when this notion of articulatory ease is applied to a theory of cluster reduction as opposed to sounds in isolation. This Articulatory Ease Hypothesis (AEH) would predict that children reduce clusters to whichever sound is easiest to pronounce (as per Figure 2.11). For example, an initial [sn] cluster would be predicted to reduce to [n] because [n] is easier to pronounce on this scale than [s]. If sounds are acquired in the same time frame, then their complexity is equated and a cluster containing both sounds would reduce equally often to each. For example, a word like *sky* would reduce to [sai] or [kai] with equal probablity, just as *musk* would reduce to [mʌs] or [mʌk]. In this way, the formerly intuitive explanation for children's cluster reductions (that children omit from a cluster whichever sound is more difficult to pronounce) is provided with a concrete measure by which sounds are assigned levels of difficulty. This makes it possible to predict the omission of one sound in a cluster over another.

With this more definitive version of an alternative hypothesis to the SH, it is now possible to consider which of the two accounts is the correct one in an experimental framework. However, with data available describing patterns in children's cluster reductions, it may not be clear why a test of the SH and the AEH requires an experimental investigation at all. The next section points out in detail the ineffectiveness of current generalizations regarding cluster reduction in choosing between the two explanations, and the consequent need for controlled inquiry.

2.7 Why Experiments?

As Chapter One makes clear, it is certainly true that many researchers have already contributed to a large number of generalizations on cluster reduction. However, a close look at the compiled data reveals its inadequacy as a means of testing the two theories in question. Consider the generalizations previously shown in Chapter One and repeated here in Table 2.5. If the observed trends are individually compared to the predictions of the SH and the AEH, it becomes apparent that none are appropriate for testing the competing accounts.

TABLE 2.5
Patterns of Cluster Reduction

Cluster Type		Reduces to:	Examples
a.	fricative+stop	stop	[ta] for *star*, [pun] for *spoon*, [kay] for *sky*
b.	stop+liquid	stop	[bu] for *blue*, [ten] for *train*, [gæs] for *glass*
c.	fricative+liquid	fricative	[fay] for *fly*, [sip] for *sleep*, [fɔg] for *frog*
d.	stop+glide	stop	[butɪfəl] for *beautiful*, [kin] for *queen*
e.	fricative+glide	fricative	[sɪŋ] for *swing*, [sɪm] for *swim*
f.	nasal+glide	nasal	[muzɪk] for *music*

The first problem with this data is that it isn't clear exactly where the data which led to these generalizations came from nor are there any specific numbers to attest to the robustness of the patterns. While Locke (1983:71) identifies these patterns as common types of cluster reduction and indicates that his findings are generally consistent with those of Vihman (1979), there is no explicit discussion of how he arrived at these generalizations and whether any statistical procedures were used. It is clear from some of his examples that he looked at numerous studies conducted by other researchers on children learning a variety of languages. Locke also includes some exceptions to these patterns, although he does maintain that these are few. Given all this, it seems important to confirm the existence of these patterns.

A second problem with the data above is the lack of information on reduction in final clusters. These clusters provide a crucial medium for testing the two theories (see §2.4). Generally, most studies on reduction at the ends of words focus on the deletion of single consonants or strings of consonants as a whole. However, there is reduction of consonant clusters to a single consonant in final as well as in initial position (Olmsted, 1971) and children's tendencies regarding these clusters are critical for a conclusive test of the hypotheses.

Lastly, likely reductions for all clusters cannot be assumed to follow wholly from the observations in Table 2.5. Note that these observations make reference to classes of sounds (e.g. a "fricative-liquid" cluster). An assumption implied by this terminology is that all clusters of a particular type will reduce in the same manner, regardless of the distinct sounds which compose those clusters. This is an especially important point because while the SH does make predictions on the basis of classes of sounds, the AEH does not. For example, in an initial [θr-] cluster, as in *throw* [θro], the SH predicts the omission of the more sonorous liquid (*throw* reduces to [θo]). The SH would make the same prediction for any other fricative-liquid cluster; i.e., the more sonorous liquid should be omitted. For example, *flow* [flo] should reduce to [fo]. However, the AEH makes predictions based on the order of acquisition of *individual* sounds. In the case of the fricative-liquid cluster [θr], the AEH would predict the omission of the fricative and not the liquid (*throw* reduces to [ro]) since [θ] is acquired after [r] and is therefore harder to produce. But given a different fricative-liquid cluster like [fl-], the AEH predicts the omission of the liquid (*flow* reduces to [fo]) because in this case the [l] is acquired after [f] and is therefore harder to produce. Thus, unlike the SH, the AEH makes a completely different prediction for a cluster of the same type, but with different segmental content. Unfortunately, the reduction of [θr-] clusters in particular and many other clusters that provide theoretically distinct predictions are not observable in the compiled data because of the way in which these data are reported (i.e. by making reference to classes of sounds with only a few individual examples).

For all of these reasons, then, I conclude that there is a need for experimental work in this domain. In order to definitively compare the two proposals, it becomes necessary to design experiments with that end in mind. This allows for the freedom to choose items that will specifically challenge the SH and at the same time distinguish it from the AEH. This work will also contribute to existing data by complementing and, in some cases, expanding the information base.

2.8 Summary and Conclusions

In the end, the main thrust of this chapter has been to present an alternative, sonority-based hypothesis of cluster reduction to challenge current articulation-based explanations. The Sonority Hypothesis maintains that in simplifying their utterances from the adult form, children choose to adhere to an optimal syllable shape over a non-optimal one. This shape is defined by laws of sonority as put forth in Clements (1990) such that syllables which adhere to these laws are the most optimal and syllables which deviate are the least optimal. The SH proposes that children reduce clusters so as to produce the most optimal syllable.

In addition, this chapter has also given some depth to the heretofore intuitive notion that constraints on children's articulatory systems are responsible for the specific cluster reductions that they make. This Articulatory Ease Hypothesis claims that children's reductions reflect the ease of pronunciation of the individual consonants such that the consonant that is omitted is the one that is more difficult to pronounce. This hypothesis provides an alternative account of the phenomenon and will make the test of the SH a more rigorous one.

It has also been made clear that in order to effectively contrast these two theories, there is a need for controlled experiments that specifically target cluster reduction. To this end, the succeeding Chapters Three and Four present two investigations into this aspect of child language.

Chapter Three: Reductions of English Clusters

"See all those bu'fies we painted?" B, 2 year old.

3. Introduction

In this chapter, I detail the specifics of Experiment One. The goal of this experiment is to elicit cluster reductions from children using a controlled set of stimuli in order to discriminate the predictions of the Sonority Hypothesis and the Articulatory Ease Hypothesis. The following, more formal definitions of these hypotheses accentuate their differences.

> **Sonority Hypothesis (SH)**. Children will reduce any initial consonant cluster, ${}^{I}C_1C_2$, to that consonant, C_1 or C_2, whose sonority value is the lesser of the two. Children will also reduce any final consonant cluster, ${}^{F}C_3C_4$, to that consonant, C_3 or C_4, whose sonority value is the greater of the two.

> **Articulatory Ease Hypothesis (AEH)**. Children will reduce any cluster, C_1C_2, to that consonant, C_1 or C_2, whose articulation is the easiest.

As discussed in the previous chapter, the most obvious difference between the two hypotheses is that the SH predicts a behavioral difference between initial and final clusters and the AEH does not. This difference is exploited in creating the stimuli for the succeeding experiment. However, in some cases, the AEH and the SH predict the same reduction for a particular cluster. For example, both theories would predict the reduction of a word like *play* to *pay* since [p] is not only the least sonorous member of the cluster, but is the more easily articulated of the two. Therefore, only clusters whose reduction would afford separable predictions between the two theories were chosen as stimuli. The set of clusters, as well as the reduced form predicted by each hypothesis, is given in Table 3.1 for the different consonant clusters used in this experiment.[1] Each cluster in the table below is modeled with an associated nonsense word. Also given are the position and natural-class type of each cluster, where (F=Fricative, S=Stop, N=Nasal, L=Liquid). (Further properties of these stimuli are discussed in §3.1.2.).

TABLE 3.1
Sample Stimuli and Predictions

	Position	Type	Cluster	Sample Item	Predictions *SH*	*AEH*
a.	Initial	F-S	[sk-]	[skub]	[s] lost	[s], [k] lost equally
b.	Initial	F-S	[st-]	[stig]	[s] lost	[s], [t] lost equally
c.	Initial	F-N	[sn-]	[snuf]	[n] lost	[s] lost
d.	Final	F-S	[-sk]	[fisk]	[k] lost	[s], [k] lost equally
e.	Final	F-S	[-st]	[dust]	[t] lost	[s], [t] lost equally
f.	Final	N-S	[-mp]	[fimp]	[p] lost	[p], [m] lost equally
g.	Final	L-S	[-lk]	[valk]	[k] lost	[l] lost
h.	Final	L-S	[-rp]	[mərp]	[p] lost	[r] lost

Note that in initial fricative-stop sequences (a,b) the SH predicts the loss of the first member of the cluster while in final fricative-stop or nasal-stop sequences (d,e,f) the loss of the second member of the cluster is predicted. By contrast, the AEH predicts that the

[1] In some cases, two forms are predicted by the AEH. This is because the individual consonants are acquired in the same time frame (cf. §2.6).

first and second members of these same clusters (a,b,d,e,f) will be lost equally. In initial fricative-nasal sequences and final liquid-stop sequences (c,g,h) the SH predicts the loss of the second member of the cluster while the AEH predicts the loss of the first member only.

With respect to some of the clusters, there are two higher order predictions of the SH to be noted. These will provide a crucial test of the SH. As pointed out in Chapter Two, while the AEH predicts the same type of reductions for all the initial and final fricative-stop clusters (a,b,d,e), the SH does not. Specifically, if the fricative-stop cluster is word-initial, then the SH predicts the loss of the fricative, [s], but if the same cluster is word-final, then the SH predicts the loss of the stop, [t] or [k]. That is, the SH predicts an interaction between cluster position and type of consonant lost: which consonant is lost is dependent on the position of the cluster in the word. Along these same lines, a second interaction is predicted by the SH, but not by the AEH, with respect to the initial fricative-stop clusters (a,b) and the initial fricative-nasal cluster (c). If the initial cluster is a fricative-stop cluster, the SH predicts the loss of the fricative, [s], but if the initial cluster is a fricative-nasal cluster, the SH predicts the loss of the nasal, [n]. That is, the SH predicts an interaction between type of consonant lost and cluster type: which consonant is lost is dependent on the type of the cluster.

3.1 Method

3.1.1 Subjects

Subjects in this experiment were sixteen English-speaking children between the ages of twenty-one and thirty-eight months. The mean age for the group was 29.8 months. All the children participating in the study lived in either Phoenix or Tucson, Arizona.

3.1.2 Materials

There were two sets of stimuli used, picture stimuli and word stimuli. The former was a set of 32 colored pictures of imaginary animals. The animals were meant to be "make-believe" and were drawn so that no resemblance to real animals would be supposed.[2] The make-believe animals were necessary so that children would not spontaneously name the animal but would instead accept a nonsense word as the label for the unfamiliar creature.

The word stimuli comprised a set of 32 nonsense words, containing eight different clusters with four nonsense words for each cluster. There were three initial clusters where items had the shape CCVC, and five final clusters where items had the shape CVCC . Items were also constructed such that no reduction of the cluster would produce a real word. For example, the nonsense word [fisk] can reduce to [fis] and [fik], neither of which are real words. However, a nonsense word such as [mɪsk] can reduce to either

[2] I am very grateful to S. Bourgeois, C. Fitzgerald, C. Gerfen, D. Kelemen, and D. Meador for helping me create the pictures for this experiment.

[mɪs] or [mɪk] where [mɪs] is a real word (*miss*) and [mɪk] is not. The rationale for using nonsense words like [fisk] and avoiding those like [mɪsk] was to eliminate any bias a child might have to reduce an item to a real word over a nonsense word.[3] (Cf. Table 3.1 for examples; see Appendix A for a complete list of stimuli).

3.1.3 Procedure

The experiment was run in each child's daycare and was usually conducted in a separate area from the child's classroom to allow for better recording of the child's productions. The task used was adapted from studies done by Prather, Hedrick & Kern (1975) which were aimed at tracking children's acquisition of speech sounds. The experimenter began the study by introducing herself to the child and suggesting that the two of them play a game together. The child was told that (s)he would see some pictures of "funny" or "silly" animals and that (s)he would be told a name for each of the animals. The experimenter then told the child that her/his part of the game would be to repeat the name of the new animal. Once the instructions were clear, the child was asked again if (s)he wanted to play the game. Given consent, the experimenter would show the child the first picture and say "This is an X (nonsense word here); can you say X?" or "This is an X; Say X." If the child did not respond, the experimenter would repeat the request up to two more times and then move on to a different item. Missed tokens were presented again later

[3] There was one item accidentally included in the study which could reduce to a real word: the item /nalk/ can reduce to /nak/ or *knock*. This item was excluded from analysis (see §3.2).

in the game. The child was required to repeat the token only once. In every case, picture and word stimuli were randomly associated, with each child receiving all 32 items. The child's responses were recorded on an analog tape-recorder and were phonetically-transcribed later by two coders naive to the purpose of the experiment.[4] Both coders transcribed all the items and agreed in 99.3% of their transcriptions.

In addition to the main testing session, another "post-test" was done with each child as close to the original session as possible (usually, this was within one or two days). The purpose of the post-test was to ensure that the child had both of the sounds in a given cluster in his/her repertoire. Otherwise, it would not be possible to say that the child's reduction was a "choice" as opposed to the only possible response given the child's articulatory limitations. The procedure was the same in the post-test as in the main testing session. However, the picture and the word stimuli were different. There were 32 new picture stimuli, while the number and type of word stimuli varied for each child depending on his/her response in the first session. Table 3.2 illustrates how the post-test items were created.

TABLE 3.2
Sample Post-Test Items: Initial Cluster

In First Session, To:		Child Responds:		Post-Test Item:		Child Responds:		Post-Test Item:	
a	[skub]	**e**	[kub]	**i**	[sub]	**m**	[sub]	**q**	[kub]
b	[sked]	**f**	[ked]	**j**	[sed]	**n**	[sed]	**r**	[ked]
c	[skoyv]	**g**	[koyv]	**k**	[soyv]	**o**	[soyv]	**s**	[koyv]
d	[skof]	**h**	[kof]	**l**	[sof]	**p**	[sof]	**t**	[kof]

[4] I am deeply indebted to D. Meador and C. Gerfen for their coding of the data.

For example, if the child responded to the tokens (a-d) in the initial testing session by omitting the [s] from the [sk-] cluster, as shown in (e-h), then the corresponding [s]-initial items (i-l) would be elicited from that same child in the post-test. On the other hand, if the child responded to the tokens (a-d) in the initial testing session by omitting the [k] from the [sk-] cluster, as shown in (m-p), then the corresponding [k]-initial items (q-t) would be elicited in the post-test. In this way, it could be determined whether a child could or could not produce both consonants in a given cluster. If the child scored less than 50% correct when trying to reproduce each set of four post-test items, then it was concluded that the child did not have command over the consonant in question. In this event, the subject's data for the corresponding cluster in the first session was not included in the overall tally of responses. Extending the above example, if the child had failed to reproduce the [s]-initial item in three of the cases (i-l) in Table 3.2 (a score of 25% correct) then the child's data for the initial [sk-] cluster in the first testing session would be omitted from the study. Such results in the post-test would reveal that the child's production of [k]-initial responses in the first testing session (e-h) was the only possibility given the child's inability to produce items with an initial [s]. The same procedure was used regardless of whether the cluster was initial or final (see Table 3.3).

TABLE 3.3
Sample Post-Test Items: Final Cluster

In First Session, To:		**Child Responds:**		**Post-Test Item:**		**Child Responds:**		**Post-Test Item:**	
a	[fisk]	**e**	[fis]	**i**	[fik]	**m**	[fik]	**q**	[fis]
b	[vɛsk]	**f**	[vɛs]	**j**	[vɛk]	**n**	[vɛk]	**r**	[vɛs]
c	[gask]	**g**	[gas]	**k**	[gak]	**o**	[gak]	**s**	[gas]
d	[nʌsk]	**h**	[nʌs]	**l**	[nʌk]	**p**	[nʌk]	**t**	[nʌs]

3.1.4 Coding of Data

Given a cluster C_1C_2, data were coded as falling into any of four possible response categories: *Only C_1 Produced*, *Only C_2 Produced*, *Cluster Correct* (i.e. both produced), or *Other*. The *Other* category included singleton consonants produced which were not either of the consonants in the given cluster as well as clusters produced that differed from the original (in either one or both consonants). Non-responses were also included in this category.

It is important to note that these results are probabilistic in nature; children's responses are not always the same 100% of the time. For example, a child might produce the word [skoyv] correctly (with a full cluster) but produce another initial [sk-] item, [sked], as reduced, [ked]. The first response would be coded as *Cluster Correct* and the second would be coded as *Only C_2 Produced.* It is then necessary to use statistical procedures to determine the existence of any significant patterns in the data. In the following section, I report only on the two relevant categories *Only C_1 Produced* and *Only C_2 Produced* (so percentages will not total 100%).

3.2 Results

Results of the post-test revealed scores of less than 50% for all children in the two conditions involving clusters containing liquids (g-h in Table 3.1). Thus, data on all final liquid-stop clusters were excluded from analysis.[5] In all other conditions (a-f in Table 3.1), children performed at levels above 50% on their post-tests. However, the total number of comparisons to be made was reduced overall to four (instead of six without liquids) by collapsing items with initial [st-] and [sk-] clusters into a single condition labeled *Initial Fricative-Stop*, and items with final [-st] and [-sk] clusters into a single condition labeled *Final Fricative-Stop*. The results of these four conditions follow and are summarized in Table 3.4.

First, examination of responses to initial fricative-stop clusters (3.4a) showed, as predicted by the SH, that there were more initial stops produced (34%) than initial fricatives (14%). Second, children responded more often with fricatives (25%) than with nasals (19%) in initial fricative-nasal clusters (3.4b). Third, again as predicted by the SH, final fricatives (42%) were produced more often than final stops (10%) in final fricative-stop clusters (3.4c). Lastly, and unexpectedly, final stops were produced more often (56%) than final nasals (3%) in final nasal-stop clusters (3.4d). A priori *t* tests by subjects

[5] Thus, /nalk/ was excluded, see fn 3.

on these comparisons revealed that differences in the final fricative-stop clusters and final nasal-stop clusters (3.4c-d) were significant, ($t(13) = 2.46, p < .05$, one-tailed) and ($t(7) = 3.79, p < .01$, one-tailed), respectively. Similar tests on the initial clusters revealed a marginally significant difference in the initial fricative-stop clusters (3.4a) in favor of stops ($t(13) = 1.54, p = .08$, one-tailed), and no significant difference (ns) in the initial fricative-nasal clusters ($t(15) = .75, p = .233$, one-tailed), although children did produce numerically more fricatives.

TABLE 3.4
Summary of Experiment One Results

Cluster Type	% C_1 Produced	% C_2 Produced	*p*	Consistent w/ SH	Consistent w/ AEH
a. Initial Fricative-Stop: st-, sk-	14	34	= .08	yes	no
b. Initial Fricative-Nasal: sn-	25	19	ns	yes	no
c. Final Fricative-Stop: -st, -sk	42	10	< .05	yes	no
d. Final Nasal-Stop: -mp	3	56	< .01	no	no

In addition to the above, two two-way analyses of variance by subjects were performed. The first compared cluster position with consonant type in the initial and final fricative-stop conditions only. There were no main effects of either cluster position or consonant type, ($F(1,13) = .104, p = .752$) and ($F(1,13) = .404, p = .536$), respectively. However, there was an interaction between these two factors which was predicted by the SH ($F(1,13) = 8.50, p < .05$). A priori *t* tests by subjects on the relevant comparisons revealed significant differences in the production of final fricatives (42%) versus final stops (10%) ($t(13) = 2.46, p < .05$, one-tailed), initial stops (34%) versus final stops (10%) ($t(13) = 1.85, p < .05$, one-tailed), and final fricatives (42%) versus initial fricatives (14%) ($t(13) = 2.15, p < .05$), with a marginal difference in the production of initial stops (34%) versus initial fricatives (14%) ($t(13) = 1.54, p = .08$, one-tailed). Figure 3.1 illustrates these effects.

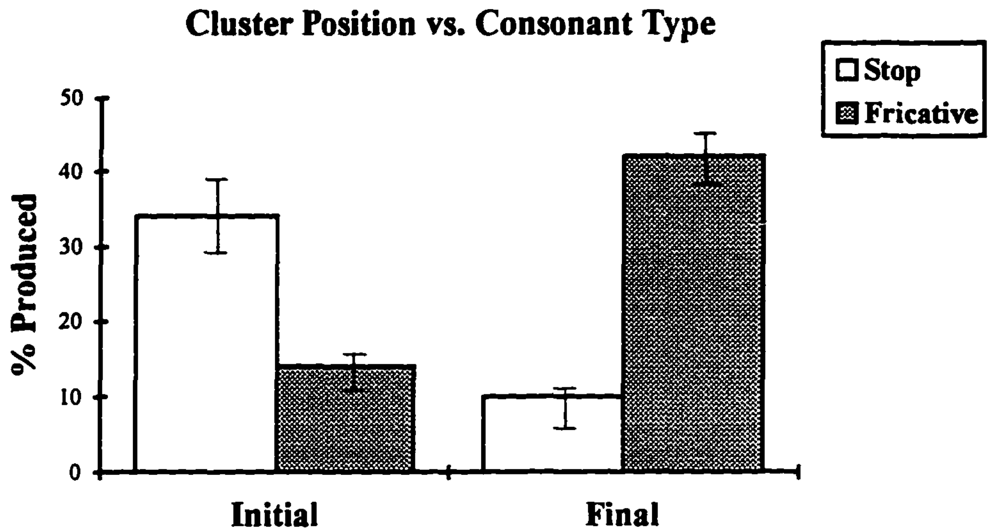

Figure 3.1. Consonants produced in initial and final fricative-stop clusters.[6]

The second two-way analysis of variance (cluster type and consonant type) was performed on initial fricative-nasal and fricative-stop clusters. Again as predicted by the SH, the interaction of these two factors was significant ($F(1,15) = 5.05, p < .05$) with no

[6] Error bars indicate the amount of variability around the mean in each condition; the longer the bar, the greater the variability. The amount of variability affects the likelihood that differences between conditions will be significant; the greater the amount of variability, the less likely there will be a significant difference.

main effects of cluster type ($F(1,15) = 1.11, p = .309$) or consonant type ($F(1,15) = .24, p = .632$). A priori t tests by subjects on the relevant comparisons, fricatives (34%) versus stops (16%) in fricative-stop clusters, fricatives (25%) versus nasals (19%) in fricative-nasal clusters, and fricatives in fricative-nasal (25%) versus fricative stop (16%) clusters, showed a significant difference in the first comparison only, ($t(15) = 2.25, p < .05$, one-tailed). See Figure 3.2 for an illustration of these effects.

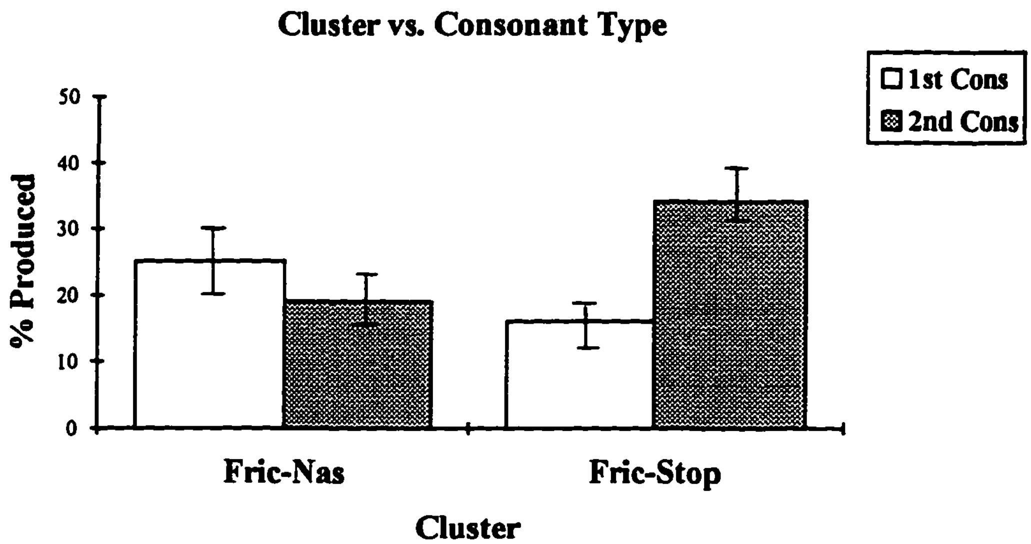

Figure 3.2. Consonants produced in initial fricative-nasal and fricative-stop clusters.

3.3 Discussion

The main findings of this experiment support the view that children's cluster reductions are sonority-driven. All but one of the predictions of the SH were borne out (see Table 3.4). The unmet prediction involves the final nasal-stop condition, [-mp], where, according to the SH, children should have reduced the cluster to a final [m]. Unexpectedly, children overwhelmingly chose to reduce this cluster to a final [p]. This result was not expected under the AEH either, which predicted equal reductions to [m] and [p]. Although this result appears puzzling in both frameworks under consideration, further discussion will reveal a possible reason for the behavior of this particular cluster. A detailed discussion of all the results follows.

3.3.1 Initial and Final Fricative-Stop Clusters

Recall that the SH predicted that in an initial fricative-stop cluster, the stop would be produced (e.g., [stig] → [tig]), but that in a final fricative-stop cluster, the fricative would be produced (e.g., [dust] → [dus]). Thus, an interaction was expected between the position of the cluster (initial or final) and consonant type (fricative or stop). Results prove this to be the case. The AEH, on the other hand, predicted an equal number of fricative and stop responses for the individual clusters regardless of the position of the cluster. These results were clearly not borne out. To make this comparison more evident, Table 3.5 displays the actual pattern of the responses obtained in these conditions, as predicted by the SH, alongside those results predicted by the AEH.

TABLE 3.5
Actual vs. Predicted Results in
Initial and Final Fricative-Stop Clusters

	Actual Pattern	SH Pattern	AEH Pattern
Initial	stops > fricatives	stops > fricatives	stops = fricatives
Final	fricatives > stops	fricatives > stops	stops = fricatives

As was noted in §3.2, the interaction predicted by the SH is borne out: stops are produced in initial clusters and fricatives are produced in final clusters. Additionally, the results expected by the AEH are plainly in contrast to the actual results.

3.3.2 Initial Fricative-Stop and Fricative-Nasal Clusters

Looking at the second of the main results of this experiment, further support for the sonority-driven view of cluster reduction is found. Recall in initial fricative-stop clusters, the SH predicted fricative omission (e.g. [stig] → [tig]). But in initial fricative-nasal clusters, the SH predicted fricative production (e.g. [snuf] → [suf]). Here, also, an interaction is expected, in this case between cluster type (fricative-stop or fricative-nasal) and consonant type (fricative vs. stop/nasal). Results prove this to be the case. According to the AEH, on the other hand, children should have i) produced more nasals than fricatives in the fricative-nasal clusters, and ii) produced an equal number of fricatives and stops in the fricative-stop clusters. Neither of these predictions holds true. Table 3.6

reveals the contrast between the actual results obtained, as predicted by the SH, and those results predicted by the AEH.

TABLE 3.6
Actual vs. Predicted Results in
Initial Fricative-Stop and Fricative-Nasal Clusters

	Actual Pattern	**SH Pattern**	**AEH Pattern**
Fricative-Stop	stops > fricatives	stops > fricatives	stops = fricatives
Fricative-Nasal	fricatives > nasals	fricatives > nasals	nasals > fricatives

Plainly, the predictions of the AEH are unsubstantiated. Children reduced initial fricative-stop clusters to stops and fricative-nasal clusters to fricatives, contradicting the claims of the AEH and supporting the claims of the SH.

3.3.3 Final Nasal-Stop Clusters

Children's productions of final nasal-stop clusters were somewhat unexpected. In final nasal-stop clusters, children were significantly more likely to omit the nasal than the stop (e.g. [gamp] → [gap]). This outcome was not predicted by either theory. The SH predicted that children should do the opposite; i.e., children should have produced the nasal and not the stop. The AEH predicted that children should have produced both nasals and stops equally often. Table 3.7 clarifies the differences between the predicted outcomes and the actual pattern of responses obtained.

TABLE 3.7
Actual vs. Predicted Results in Final Nasal-Stop Clusters

Actual Pattern	SH Pattern	AEH Pattern
stops > nasals	nasals > stops	stops = nasals

One possible explanation of these anomalous results concerns the nature of the sequence "...vowel-nasal-stop" word-finally in English. It has been claimed that this particular sequence does not actually contain a cluster. As early as Malécot (1960), but also in Hooper (1977) and Kaisse (1985), it has been noted that in tautosyllabic sequences such as these in American English, there is a nasalized vowel but no nasal consonant. That is, adult speakers of English will pronounce a word spelled with a final vowel-nasal-consonant sequence, like *romp*, as a nasalized vowel-consonant sequence, [rɔ̃p]. That this is true is further supported by psycholinguistic evidence from research done by Treiman, Zukowksi, & Richmond-Welty (1995). In studies investigating children's spelling errors, they found that English-speaking, first-grade children will spell a word like *lamp* as "l-a-p", indicating children's intuition that the nasal is really part of the vowel and not an independent consonant.

Given these facts, the results for final nasal-stop clusters can be explained. The nonsense words containing final nasal-stop "clusters" did not, in fact, have a cluster at all. Rather, children heard sequences of a nasalized vowel followed by a single stop consonant. Thus, the notion of cluster reduction does not even apply here. More than half the time, children faithfully reproduced an item ending in a single, final [p]. Whether or not the preceding vowel was produced with nasalization is another question. Coders were instructed to transcribe these items with nasalization if they heard it. However, coders indicated that this was very hard to hear and while some children were transcribed as producing [gãp] and others [gap], the presence or absence of the nasalization is questionable and so is subject to further investigation.

3.4 Summary and Conclusions

In conclusion, this experiment has shown that children's cluster reductions are indeed driven by considerations of sonority. The expected interactions as predicted by the SH were shown to exist, first in the initial and final fricative-stop clusters and then in the initial fricative-stop and fricative-nasal clusters. These interactions cannot be explained by the AEH. The findings in the final nasal-stop condition were shown to support the existing notion that such sequences are not clusters but are realized as a nasalized vowel followed by a single stop.

While these results are encouraging in their support for the application of sonority theory to cluster reduction, there are some concerns which should be addressed. In the end, there was not a great variety in the type of clusters used in this experiment. All of the analyzable clusters contained an [s], either initially or finally. Further, three of the eight original conditions were subsequently shown to be either unusable (the final liquid-stop clusters) or irrelevant (the final nasal-stop clusters). These concerns are taken up in the next experiment which is detailed in Chapter Four.

Chapter Four: Reductions of non-English Clusters

"Our gog is not named temaud." B, 2 year old.

4. Introduction

In this chapter, I present and discuss the specifics of the second of the two experiments on cluster reduction. This study was undertaken in an effort to increase the variety of stimuli tested in order to ensure that the Sonority Hypothesis generalizes to many cluster types. Unfortunately, there were no clusters in English, other than the ones used in the first experiment, which would distinguish the two hypotheses. As noted in §3.2, it was determined in the post-test that children were unable to reliably produce single liquid consonants. Thus, all /Cr-/, /Cl-/, /-lC/, and /-rC/ clusters were necessarily excluded from the present experiment (where C=Consonant). Clusters containing equally late-emerging sounds (for example, [θ] and [ð]) were also barred from consideration.[1] Therefore, it was necessary to construct the word stimuli for this second experiment using non-English clusters. Since the claims of the sonority theory are generally assumed to be applicable to all languages (and are, in fact, based on cross-linguistic observations of syllable structure), the SH should also be able to predict the pattern of children's reductions in non-English stimuli. More specifically, the predictions of the SH should adhere to the same principles whether or not a cluster occurs in the child's native

[1] In fact, a pilot version of Experiment One included a [θr] cluster. This was excluded from the later study because children in the necessary age range were not able to reproduce this sound with any accuracy.

language: if a cluster is initial the most sonorous member will be omitted; if a cluster is final the least sonorous member will be omitted. Table 4.1 gives some examples of non-English clusters and indicates the predictions of each hypothesis with respect to those clusters.

TABLE 4.1
Sample Stimuli and Predictions

	Position	Type	Cluster	Sample Item	Predictions *SH*	*AEH*
a.	Initial	S-F	[tf-]	[tfuk]	[f] lost	[t] lost
b.	Initial	S-N	[tm-]	[tmaud]	[m] lost	[t] lost
c.	Initial	S-G	[bw-]	[bwɪv]	[w] lost	[b] lost
d.	Initial	F-N	[fn-]	[fnug]	[n] lost	[f] lost
e.	Initial	F-G	[fw-]	[fwim]	[w] lost	[f], [w] lost equally
f.	Initial	N-G	[mw-]	[mwib]	[w] lost	[m], [w] lost equally
g.	Final	S-F	[-pf]	[mɛpf]	[p] lost	[f], [p] lost equally
h.	Final	F-S	[-fp]	[gɪfp]	[p] lost	[f], [p] lost equally

Note that in (a-d), the two hypotheses predict the opposite results. The SH predicts the loss of the first member of the cluster in these cases, while the AEH predicts the loss of the second member. In (e-g), the SH still predicts the loss of the first member of the cluster and in (h) the loss of the second member, but the AEH predicts that both members of the given cluster should be omitted equally often (in e-h).[2]

[2] With respect to the predictions of the AEH, there is an important contrast to note between (a) and (g,h). Despite the fact that all three clusters contain stops and fricatives, the predictions are different for (a) versus (g,h). In (a), the segments of the cluster are [t] and [f]. Under the AEH, since [t] is more difficult to pronounce than [f] (cf. §2.6), it follows that the [t] (the stop) should be omitted. However, in the other two stop~fricative clusters (g,h), the segments are [f] and [p]. In this case, the AEH predicts the loss of the

Aside from these predictions, one final property of the clusters listed in Table 4.1 should be discussed. While none of the clusters occur in English, some of them are phonologically similar to clusters that do. For example, in English there are no words beginning with [bw-], but there are words beginning with other stop-glide clusters, such as [tw-] and [dw-] (as in *twin* and *Dwayne*) and [kw-] and [gw-] (as in *queen* and *Gwen*). However, there are no words at all in English that begin in a stop-fricative cluster, like [tf-]. In this way, the clusters in Table 4.1 can be divided into two groups according to their similarity to clusters existing in English (i.e. whether or not there is another cluster composed of the same class of sounds in the language). The unshaded rows (c, d, e, g, and h) contain clusters which have a similar counterpart in English while the shaded rows (a, b, and f) contain clusters which have no similar counterpart in English. This difference is noted because, despite the fact that children will not have heard any of the clusters in this experiment before, there may yet be an effect of similarity. If a child has heard a cluster similar to the ones in the experiment, (s)he may treat that cluster differently than ones which (s)he has not.

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fricative or stop equally often as they are equated articulatorily. Thus, the same type of cluster reduces differently depending on the segmental content of that cluster.

4.1 Method

4.1.1 Subjects

Sixteen English-speaking children all living in Tucson, Arizona took part in the experiment. The children ranged in age from twenty-five to thirty-seven months with a mean age of 31.4 months.

4.1.2. Materials

The same number of items and conditions (or clusters) were used in this experiment as in the first study (8), as was the identical set of pictures (32 test session, 32 post-test). The word stimuli were necessarily different in content but were still either of the form CCVC or CVCC. (Cf. Table 4.1 for examples; see Appendix B for a complete list of stimuli).

4.1.3 Procedure

This study was performed in the same manner as Experiment One (see §3.1.3). However, all of the sessions in this study were recorded on a digital-analog tape recorder rather than an analog tape recorder. This was done in order to obtain better sound quality. Coder agreement was 99%.[3]

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[3] I am in further debt to D. Meador and also to P. Pérez for coding the data.

4.1.4 Coding of Data

Data were again coded as falling into any of four possible response categories: *C_1 Produced*, *C_2 Produced*, *Cluster Correct*, or *Other*. However, there was one difference in the coding procedure. The categories *C_1 Produced* and *C_2 Produced* were not restricted to the two identical sounds of the cluster as was done in the first experiment. Rather, these categories included singleton consonants produced which were either identical to one of the consonants in the original cluster or were a member of the same natural class as one of the consonants. For example, a child's response would be recorded as *C_1 Produced* if in response to [fnug] the child said either [fug] or [sug], where the [s] is a fricative just like the original [f]. The rationale behind this change was that the SH makes predictions based on classes of sounds (see §2.7), such that, for example, an initial fricative-nasal cluster reduced to any fricative is better than one reduced to any nasal. Thus, the exact identity of the sound produced is not as important as the class to which the sound belongs. This way of coding responses was necessary to this experiment because, unlike in Experiment One, children were much less accurate and did, in fact, produce many substitutions of the type described.[4] All other coding categories followed the same criteria as in the first experiment.

[4] In fact, coding the data in this way, as opposed to the procedure used in the first experiment, does not change the basic results with the exception of the [fn-] clusters. See §4.3.4 for an explanation.

4.2 Results

In this study, the post-tests indicated children's ability to reliably and accurately pronounce all of the sounds in the clusters tested. Therefore, the following presentation of results includes all eight comparisons. (See Table 4.2 for a summary). With the exception of one case, analyses of variance by subjects revealed that all differences between C_1 *Produced* and C_2 *Produced* were significant. First, children most often produced fricatives (80%) as opposed to stops (9%) in response to initial stop-fricative clusters (4.2a) ($F(1,15) = 28.58$, $p < .001$). For initial stop-nasal clusters (4.2b), children were more likely to respond with nasals (45%) than stops (2%) ($F(1,15) = 21.00$, $p < .001$). In initial stop-glide clusters (4.2c), stops were more frequently produced (42%) than glides (13%), as predicted by the SH ($F(1,15) = 7.98$, $p < .05$). In the case of initial fricative-glide clusters (4.2e), children most often responded with fricatives (39%) over glides (14%), also as predicted by the SH ($F(1,15) = 5.06$, $p < .05$). In nasal-glide clusters (4.2f), glides were produced more often than nasals (70% vs. 8%) ($F(1,15) = 50.00$, $p < .001$). Again as predicted by the SH, in the final fricative-stop and stop-fricative clusters (4.2g-h) children responded more often with fricatives (59% and 52%) than stops (16% and 16%), ($F(1,15) = 34.28$, $p < .001$) and ($F(1,15) = 12.42$, $p < .01$), respectively. Lastly, there were more nasals produced (39%) than fricatives (19%) in initial fricative-nasal clusters (4.2d), but this difference was not significant ($F(1,15) = 2.54$, $p = .132$). In the table below "ns" = "not significant".

TABLE 4.2
Summary of Experiment Two Results

Cluster Type	% C_1 Produced	% C_2 Produced	*p*	Consistent w/ SH	Consistent w/ AEH
a. Initial Stop-Fricative: tf-	9	80	< .001	no	yes
b. Initial Stop-Nasal: tm-	2	45	< .001	no	yes
c. Initial Stop-Glide: bw-	42	13	< .05	yes	no
d. Initial Fricative-Nasal: fn-	19	39	ns	no	yes
e. Initial Fricative-Glide: fw-	39	14	< .05	yes	no
f. Initial Nasal-Glide: mw-	8	70	< .001	no	no
g. Final Stop-Fricative: -pf	16	52	< .01	yes	no
h. Final Fricative-Stop: -fp	59	16	< .001	yes	no

4.3 Discussion

The main findings of this experiment are consistent with those of Experiment One; results support the notion that children reduce clusters according to considerations of sonority. However, there were some interesting consequences of using non-English clusters in this study which must be noted and explained. At first glance, it appears that only half of the eight conditions patterned according to the SH (the shaded rows in Table 4.2; call this "Group One"), while the other half clearly did not (the unshaded rows; call this "Group Two"). This is in some sense unsurprising as a comparison of the two groups reveals an effect of similarity to English, the possibility of which was mentioned in §4. When viewed in this light, it becomes clear that children applied the SH to those clusters which were similar to English clusters (with the exception of the fricative-nasal cluster /fn/, see §4.3.4). On the other hand, when children were confronted with clusters which were not at all similar to native clusters, they applied different rules for incorporating these clusters into their repertoire, the nature of which will be discussed shortly.

4.3.1 Group One

Figure 4.1 illustrates the findings in the four conditions where the predictions of the SH held. In initial stop-glide clusters and fricative-glide clusters (the gray bars), children were expected to produce the stop and the fricative, respectively. In final fricative-stop clusters and stop-fricative clusters (the white bars), children were expected to produce the fricative in both cases. All four of these predictions were borne out.

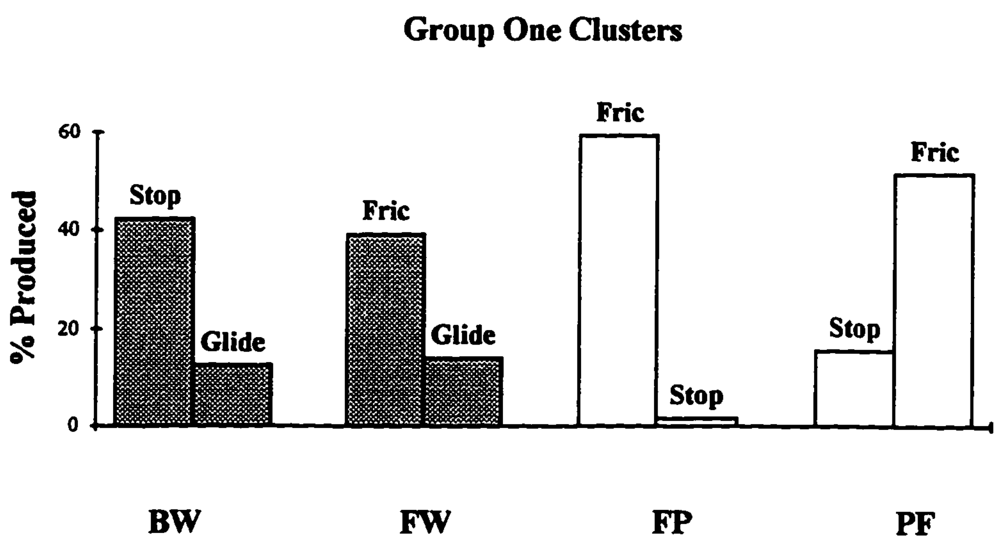

Figure 4.1. Results of Group One ("English-like") Clusters, whose results support the predictions of the SH.

The AEH, on the other hand, is unable to explain these effects. Only the SH is capable of accounting for children's performance with these clusters. To make this claim more evident, Table 4.3 displays the predictions of both theories alongside those results actually obtained.

TABLE 4.3
Actual vs. Predicted Results for Group One Clusters

	Actual Pattern	SH Pattern	AEH Pattern
Initial Stop-Glide	stops > glides	stops > glides	glides > stops
Initial Fricative-Glide	fricatives > glides	fricatives > glides	fricatives = glides
Final Fricative-Stop	fricatives > stops	fricatives > stops	fricatives = stops
Final Stop-Fricative	fricatives > stops	fricatives > stops	fricatives = stops

4.3.2 Group Two

The four conditions of this group are those whose results were ultimately the most interesting. In these cases, the predictions of the SH were not supported. In two conditions, the initial stop-fricative ([tf-]) and stop-nasal clusters ([tm-]), children responded by omitting the stop. The SH predicted the opposite effect: children should have responded by producing the stop and omitting the second member of the cluster. In fact, the actual findings are consistent with the AEH. Table 4.4 compares the actual results of these conditions with those predicted by both the AEH and the SH.

TABLE 4.4
Actual vs. Predicted Results for Stop-Fricative and Stop-Nasal Clusters

	Actual Pattern	AEH Pattern	SH Pattern
Initial Stop-Fricative	fricatives > stops	fricatives > stops	stops > fricatives
Initial Stop-Nasal	nasals > stops	nasals > stops	stops > nasals

Plainly, the actual pattern of responses obtained for these two clusters goes against the predictions of the SH. This is also the case for the remaining clusters, although the last two cluster types under consideration pose problems for both theories. In the initial nasal-glide clusters ([mw-]), children should have responded by omitting the glide and producing the nasal, according to the SH. The AEH, on the other hand, would have predicted that children would produce both the nasal and the glide equally often. Neither of these outcomes was realized. In fact, children responded significantly more often with the glide. Table 4.5 clarifies the difference between the actual results and those predicted by the two theories.

TABLE 4.5
Actual vs. Predicted Results for Nasal-Glide Clusters

Actual Pattern	AEH Pattern	SH Pattern
glides > nasals	glides = nasals	nasals > glides

Somewhat similar problems occur in the case of the initial fricative-nasal clusters ([fn-]). Table 4.6 shows the actual and predicted outcomes.

TABLE 4.6
Actual vs. Predicted Results for Fricative-Nasal Clusters

Actual Pattern	AEH Pattern	SH Pattern
nasals = fricatives	nasals > fricatives	fricatives > nasals

The SH predicted that children would produce the fricative and omit the nasal. The AEH predicted the opposite: children should have produced the nasal and omitted the fricative. In fact, there was no significant difference between the number of nasals and fricatives produced. In these conditions, then, the results are in no way the expected ones according to the SH.

Overall, there are four conditions whose results fall out as expected by the SH and four whose results do not follow from either the SH (in all four cases) or the AEH (in at least two cases). The question can now be addressed as to why this latter group of conditions should behave so differently from the group identified earlier in §4.3.1. A substantive difference between these two groups has already been noted, and it is this difference which will make sense of the seemingly anomalous results found here.

4.3.3 Group One vs. Group Two

Earlier in the chapter, it was explained that some of the clusters used in this experiment resembled possible English clusters more closely than others. The clusters identified as having similar counterparts in English were [bw-], [fw-], [-fp], [-pf], and [fn-]. Clusters identified as having no similar counterpart in English were [tf-], [tm-], and [mw-]. It is almost precisely these groups that have been noted as behaving differently per the results of this experiment. With the exception of [fn-] (to be discussed later in §4.3.4), all of the "similar" clusters behave in accordance with the SH (Group One). All of the "non-similar" clusters do not (Group Two, exclusive of [fn-]). This would suggest that when children hear clusters that are unfamiliar, as they did in this study, they react by comparing what they hear with what they know. In the case of Group One clusters, children had a basis for comparison for the novel clusters and consequently treated them in the same manner as their counterparts. That is, their cluster reductions in these four conditions were sonority-driven. However, when children were confronted with clusters whose composition was completely unfamiliar ([tf-], [tm-], [mw-]), they reacted quite differently.[5] In fact, the proposal is that when and if children correctly understood the composition of the latter clusters, they interpreted them as having two syllables. That is, an item such as [tfuk] was interpreted as [təfuk]. The subsequent reduction of the form to [fuk], following the loss of the initial weak syllable C_1V, is then due to the well-documented process of weak-syllable deletion (see Gerken, 1994) and is not due to a process of cluster reduction.

Support for this analysis can be found in an examination of subject's errors. First, an investigation of children's responses coded *Cluster Correct* and *Other* reveals that

[5] But note that children were able to produce the individual members of the clusters exactly, as was determined by the post-tests. Thus, it is the composition of the two consonants into a cluster that causes difficulties for the children.

children produced more incorrect responses for the clusters of Group Two and more correct responses for the clusters of Group One. Figure 4.2 shows these comparisons.

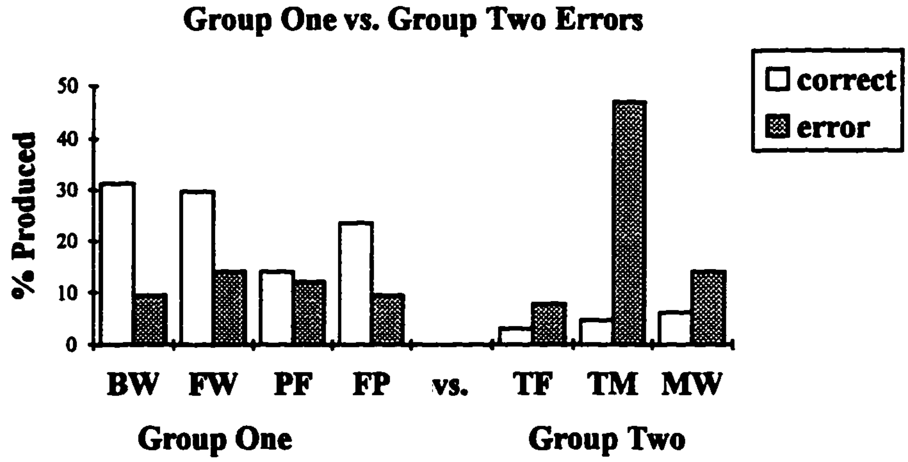

Figure 4.2. Errors in Group One Clusters ([bw-], [fw-], [-pf], [-fp]) vs. errors in Group Two clusters ([tf-], [tm-], [mw-]).

This array of correct responses and errors indicates children's understanding of the composition of the clusters of Group One, since they were able to repeat the cluster correctly more often than not. The clusters of Group Two, on the other hand, were clearly not understood as well since children more often replied with an incorrect response (i.e. no response, responses containing more consonants than in the original cluster, responses containing extra syllables, and responses containing consonants different in natural class from the original consonants in the cluster).

Perhaps more compelling evidence for the analysis in question is the fact that among children's errors for Group Two clusters there were epenthesized forms, or forms containing an extra syllable. That is, when asked to repeat an item such as [tmaud], children sometimes responded with [təmaud]. However, children never responded with a two-syllable answer for any of the clusters of Group One (see Table 4.7 for the exact numbers). These facts would suggest that items with Group One clusters were correctly interpreted as having only one syllable.

TABLE 4.7
Number of Epenthesis Errors
in Group One vs. Group Two Clusters

Group One	0
Group Two	8

This is exactly the kind of evidence that one would hope to find to substantiate the idea that these two groups of clusters behaved differently in a systematic way. The clusters of Group One, those with similar English counterparts, were clearly understood by the children to contain only one syllable, as indicated by the number of correct responses over errors and the lack of epenthesized errors. These items were reduced exactly as predicted by the SH. The clusters of Group Two, on the other hand, those with no English counterparts, were clearly not understood much of the time and often were interpreted as having two syllables, as indicated by the number of errors over correct responses and the presence of the epenthesized forms. These items were reduced to the second consonant of the "cluster", where the SH predicted the omission of that consonant. However, these reductions pose no threat to the SH given that children interpreted them as two-syllable items. Then, the reduction of items such as [təmaud] to [maud] is a reduction due to the deletion of a weak syllable and not to the reduction of a cluster at all.

4.3.4 Fricative-Nasal Clusters

Having now shown that the seemingly anomalous results for the clusters [tf-], [tm-], and [mw-] of Group Two were not due to some failure of the SH, it is necessary to address the fourth cluster in that group, [fn-]. As was shown in §4.3.2, children did not respond with either consonant of this cluster significantly more often than the other, although the trend is for a higher production of nasals. This result was noted as being inconsistent with the SH, which predicted a significantly higher production of fricatives. However, at first glance, consideration of a similarity effect does not clear up the results as it did with the other members of Group Two. The cluster [fn-] does, in fact, have similar counterparts in English (namely, [sn-] and [sm-]) and by the proposal just given, should pattern with the clusters of Group One. That is, children should reduce this cluster according to the SH. In addition, error analyses for [fn-] indicate a similar inconsistency of results. Children responded more often with correct responses than not as was true for members of Group One, but there were also epenthesized forms found, such as [fənug], as was true for members of Group Two. Thus, in some cases it looks as if the fricative-nasal cluster should be considered part of Group One, the "similar" clusters, but in other cases it looks as if this cluster should be considered part of Group Two, the clusters with no English counterparts. This intermediate status of [fn-] appears to be directly reflected in the findings for this cluster since it did not pattern according to the SH (in this case by retaining the fricative) like other Group One clusters, nor did it exhibit weak-syllable deletion (in this case by leaving the nasal) like other Group Two clusters. Instead, both consonants were produced equally often.[6]

The reason for this lies in a more refined definition of similarity. Initially, a non-English cluster was similar to an English cluster if another cluster of that same class could be found in the language. Thus, [bw-] shows an effect of similarity because there are other stop-glide clusters in English, such as [tw-] and [kw-]. By the same token, [fn-] should show an effect of similarity because there are other fricative-nasal clusters in English, [sn-] and [sm-]. However, fricative-nasal clusters should not be fully equated with [bw-] clusters because fricatives cannot combine as freely with nasals in English as can stops with glides. In fact, [s] is the only fricative in English that can combine with a nasal whereas stop-glide clusters can be formed with more than one stop. In this sense, then, the measure of whether a non-English cluster is similar to an English cluster is a gradient one rather than a strict one. Under this conception, a spectrum of similarity going from least to most would have [tf-] at the least similar end and [bw-] at the most similar end, and [fn-] would be somewhere in the middle. Under this view, children's ambiguous responses to the [fn-] clusters in this experiment are not so puzzling. Given the dual nature of the

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[6] It is in this condition that the results are different if the data is coded without including substitutions (as was done in Experiment One). In that case, there is a significantly greater number of nasal responses ($p < .05$). These results obtain precisely because there were a large number of substitutions in this category (and in others compared to Experiment One). Many children responded with [s] instead of [f]. If data is coded for an exact response, then these [s] responses are coded as *Other*. This obscures the fact that children are responding with a fricative over a nasal. The present coding method reveals this fact and is thus more appropriate for the purposes of this experiment.

fricative-nasal cluster in terms of similarity (i.e. not as similar to English clusters as [bw-] but not as dissimilar as [tf-]), the dual nature of the results is expected. Under the current proposal, this cluster would be predicted to behave neither in accordance with the SH (i.e. significantly more fricatives) nor in accordance with the weak-syllable deletion process (i.e. significantly more nasals). Results show that this is exactly the case: both the fricative and the nasal are produced equally often by children.

4.4 Summary and Conclusions

In sum, the goal of this study was to test the SH with a wider variety of clusters. This experiment has, in fact, shown further support for the hypothesis that children's cluster reductions are sonority-driven. The use of non-English clusters strengthened the claims of the SH as well as exposed an interesting effect of similarity to English. Non-English clusters which were most similar to English clusters underwent cluster reduction according to the SH, while non-English clusters which were completely dissimilar to English clusters underwent a process of weak-syllable deletion. Clusters which were neither strictly similar nor strictly dissimilar to English clusters exhibited characteristics of both.

On a larger scale, this research on cluster reduction speaks to several other concerns important to the general study of child phonology, such as the significance of parallels between cross-linguistic and child language data. The purpose of Chapter Five is to raise these concerns as they are brought out in the data, as well as to determine the parameters for a formal model of phonological acquisition that would successfully address these issues. This is done in the context of an Optimality Theoretic analysis of the cluster reduction data.

Chapter Five: Towards a Formal Model of Phonological Acquisition

"Do you have blankies at home?" D, 27 year old.
"I have Winnie-the-Pooh bankies." B, 2 year old.

5. Introduction

Thus far in the thesis I have advanced and supported a particular theory of cluster reduction in child language. In so doing, I have taken advantage of the already well motivated theory of sonority in adult phonology to provide an explicit explanation of children's non-random, specific, and cross-linguistically consistent reductions. What has not yet been addressed to this point are the larger implications of this research both for the analysis of cluster reduction presented in this work and for theories of child phonology in general. In fact, the particular research paradigm employed in this dissertation raises at least four issues whose resolution, I believe, is critical to any successful theory of phonological acquisition. These are: i) the existence of significant parallels between child language and adult cross-linguistic patterns, ii) the existence and the effect of variability in child data, (iii) the existence of numerous stages of development in child phonology, and (iv) the existence of asymmetries between children's production and comprehension of utterances.

The purpose of this chapter is first to discuss these issues in detail, and then to consider how best to account for them in a formal model of phonological acquisition. The latter goal will be accomplished by advancing one possible model of child phonology that takes as its main concern the need to specifically address the existence of parallels between children's early productions and linguistic universals. To this end, a complete Optimality Theoretic (Prince & Smolensky, 1993) analysis of the cluster reduction data is presented. The analysis is capable of providing a unified model of this phenomenon and the lack of the same in adult speech. Following this, the chapter examines the nature of such a model and concludes by questioning how well it addresses all of the crucial issues raised previously when taken as a larger theory of phonological acquisition.

5.1 Issues in Phonological Acquisition

5.1.1 Child Phonology and Linguistic Universals

One assumption of the Sonority Hypothesis is that a specific and significant relationship exists between cross-linguistically attested patterns in adult language and early child data; another assumption is that a theory that is able to account for the former should also be able to account for the latter. Subsequent experimental investigation proved these two assumptions to be valid ones by showing that syllable shapes resulting from children's cluster reductions mirrored, as closely as possible, cross-linguistically preferred syllable shapes as defined by Sonority Theory. This research has thus reified the existence of substantial parallels between children's early productions and adult cross-linguistic patterns (or linguistic universals). While these parallels have been remarked upon by earlier researchers such as Jakobson (1941) and Stampe (1979), this work has put these observations on a firmer empirical/experimental footing by establishing a clear correspondence between the output of children's cluster reductions and the most preferred syllable types across languages. While it has been argued that not all patterns found in children's early utterances reflect patterns found in adult languages (Reiss & Hale, 1996), the fact remains that a number of such parallels do exist. A theory of phonological acquisition, then, must also be able to address (and ideally predict) this relationship between child data and cross-linguistic tendencies.

5.1.2 Variability

While it is important to extract general patterns in child phonological data and to account for them, it is also important to recognize that they are, in fact, general patterns and as such are not strictly adhered to by children one hundred percent of the time. As mentioned in §3.1.4, the patterns of cluster reduction identified in this dissertation were extracted from children's overall responses to experimental stimuli using statistical procedures. This means that despite the significant number of children who responded according to the Sonority Hypothesis, still there was a small percentage of children who responded differently. Further, the same child often varied quite freely from token to token, at one time producing the full cluster, the next time reducing the cluster, and the next time producing something utterly foreign (e.g. a three or four consonant string followed by a vowel).

In general, this kind of variability is quite prevalent in child data (Locke, 1983; Menn, 1983; among others). Children often produce the same word in different ways from day to day, hour to hour, and even minute to minute. For example, Ferguson (1986) reports one 15 month old child's production of the word *pen* [p^{h}ɛ̃n] as [mã^{ʔ}], [ṽ], [dɛ$^{dn̩}$], [hm̩], [^{m}bõ], [p^{h}m̩], [t^{h}n̩t^{h}n̩t^{h}n̩], [ba^{h}], [dhauɴ], and [buã], in one thirty minute period. The question that arises then is how to incorporate both the significant patterns and the variability found in child speech into one theory of phonological acquisition. That is, at the same time as a hypothesis like the Sonority Hypothesis accounts for children's general tendencies, it must also allow room for the variability found in child speech.

5.1.3 Phasal Development

Similar to the question of variability is the question of children's progression from one stage in their productions to another. The data reported on in this dissertation is representative of only one such phase in children's phonological development. At some point, children will advance to a stage where all clusters will be produced in full, all of the time. It is possible, too, that there are other intermediate stages where some clusters are produced correctly and others are not. Phasal development has been documented in other child phonological phenomena as well. For example, Demuth (1994) posits three stages in children's development of prosodic structure in languages. (See also Donegan & Stampe, 1979; Stampe, 1979; Fee, 1992; Demuth & Fee,1995; among others).

The problem to be resolved with respect to this issue then is twofold: a theory must be able to account for children's development from stage to stage (i.e., it must account for what causes phasal change), and it must also be able to accurately predict the course of development that children enact (i.e., it must account for the nature of the phases themselves).

5.1.4 Asymmetries in Comprehension and Production

Another issue brought out by the research presented here can best be exemplified by an interchange that occurred between one child and the experimenter. The child was shown a picture of a novel animal and told that the animal was called a [snuf]. When asked to repeat the name for the animal, the child responded with [suf]. The child was congratulated on remembering the name, and the experimenter moved on to the next item. However, before the next picture was introduced, the child turned to the experimenter and said: "A [snuf]?".

It can be implied from this interchange that the child recognized that her original production of the animal name was not the same as the adult form given to her. In this case, the child was able both to recognize this difference and to articulate the adult-like response on her second attempt. In most cases, however, children comprehend the difference between their own utterances and the adult targets, but are unable to produce the adult form. This claim is supported by much anecdotal evidence indicating that a child is unwilling to accept an adult's production of a word that mimics the child's own (e.g., an adult's pronunciation of *spoon* as [pun] is unacceptable to the child even though the child's own pronunciation is [pun]) (Smith, 1973).

This type of data highlights the fact that children's productions are often limited in contrast to their advanced comprehension skills. The question that arises is how to account for this asymmetry under one model of phonological acquisition. A successful theory must be able to explain children's rich comprehension of the adult language alongside their poor production of adult forms.

5.1.5 Summary

In sum, there are at least four issues raised specifically by the data presented in this work that are important considerations for any formal model of phonological acquisition: variability, phasal development, comprehension~production asymmetries, and correspondences between linguistic universals and child phonological data. Having identified these concerns, the next step is to consider the nature of a framework that would be responsible to all of them. One place to start is to propose a model that addresses one of these issues in particular and then to examine how well the model in question residually resolves (or not) the other issues raised. To this end, the next section details an analysis of the cluster reduction data in the Optimality Theoretic framework (Prince & Smolensky, 1993; McCarthy & Prince, 1995) which takes as its main goal the ability to successfully address the relationship between children's early productions and adult cross-linguistic patterns.

5.2. One Possible Model of Phonological Acquisition

The purpose of this section is to first examine a particular account of cluster reduction that incorporates the Sonority Hypothesis into the larger framework of Optimality Theory. This will allow for a subsequent discussion of the pros and cons of one possible theoretical account of cluster reduction and, perhaps, of child phonology in general. Before providing the specific analysis, however, a discussion of Optimality Theory and its relation to the present work is in order.

5.2.1. Background on Optimality Theory (OT)

OT is a framework that was initially developed to account for adult phonological phenomena (Prince & Smolensky, 1993). Its basic claims are that a grammar is comprised of a set of ranked, universal constraints governing the well-formedness of utterances. While all speakers possess the same set of constraints (i.e., the set of constraints is innate), the ranking of the constraints is language specific. In addition, constraints are violable, but violations are only permitted when there is a conflict between a higher-ranked and a lower-ranked constraint. In this case, violations of the lower-ranked constraint are tolerated in order to satisfy the demands of the higher-ranked constraint. Finally, there is a function referred to as GEN, which provides, for any lexical input, a set of output candidates to be evaluated by the constraint ranking. The candidate that best satisfies the constraint hierarchy in a given language is chosen as the optimal phonological output.

In general, there are two types of constraints available in the universal set. One type evaluates the structural well-formedness of utterances. Prince & Smolensky (1993) propose constraints like NO CODA, HAVE ONSET (henceforth ONSET), and *COMPLEX which state that syllables must not have codas, must have onsets, and must not associate more than one C or V to any syllable position node, respectively. These constraints are reflective of linguistic universals, which suggest that preferred (or well-formed) syllables are of the shape CV (cf. §2.1). A second type of constraint evaluates the relationship between the lexical input and the output of the grammar. These constraints are known as FAITHFULNESS constraints (henceforth FAITH) and together demand an identity relationship between the input and the output, such that all the segments in the input have a correspondent in the output (McCarthy & Prince, 1995). This effectively prohibits deletion or insertion of material.

Some Examples of Constraint Rankings

To illustrate how these constraints work together to comprise a grammar, consider just the constraints NO CODA and FAITH. With only these, there are just two possible constraint rankings: NO CODA can be ranked above FAITH (NO CODA >> FAITH), or FAITH can be ranked above NO CODA (FAITH >> NO CODA). These two rankings define two different types of languages. The first ranking, NO CODA >> FAITH, defines a language where syllables with codas simply do not occur (like Hawaiian; see Andrews, 1978; Elbert & Pukui, 1979). In this case, open syllables (those without codas) must be maintained at all costs even if this means being unfaithful to the input. This outcome is depicted in Table 5.1 for any input string CVC.[1]

TABLE 5.1
NO CODA >> FAITH

		/CVC/	NO CODA	FAITH
☞	a.	CV		*
	b.	CVC	*!	

In this case, candidate (a) receives a violation of FAITH because the coda consonant in the input is not represented in the output. Candidate (b) receives a violation of NO CODA because the syllable contains a coda. However, because NO CODA is ranked above FAITH it is the second candidate's violation that is fatal. No syllables with codas are tolerated in a grammar with this constraint ranking, and so the first candidate, CV, is chosen as the preferred output.

The second possible ranking, FAITH >> NO CODA, defines a language that permits syllables to have codas (like English). In this case, it is more important that all segments of the input are represented in the output than to maintain coda-less syllables. Table 5.2 shows how any input CVC would fare under this ranking of the constraints.

[1] By convention, the input (enclosed in slanted brackets), and the output candidates to be evaluated are listed in the far left column. The constraints themselves are displayed in the first row of the tableau with the highest ranking constraint at the leftmost edge of the ranking. A double-line between constraints indicates strict ranking. Violations are indicated by an asterisk (*) or in the case of a fatal violation (one that rules out a particular candidate), an asterisk followed by an exclamation point (*!). Winning (or optimal) candidates are indicated by a pointing finger (☞). Shading indicates that once a candidate is ruled out by a higher ranking constraint, violations of lower ranking constraints are irrelevant.

TABLE 5.2
FAITH >> NO CODA

		/CVC/	FAITH	NO CODA
	a.	CV	*!	
☞	b.	CVC		*

In this case, while the violations incurred for each constraint are the same as in Table 5.2, it is candidate (b) that is chosen as the optimal output. This is because a grammar with this constraint ranking tolerates no unfaithfulness to the input, so a violation of no coda is tolerated in order to satisfy the higher ranking FAITH constraint. Thus, the same constraints are capable of depicting two separate languages (or grammars) depending on how the constraints are ranked with respect to each other.

Consider now, in one final exercise to solidify an understanding of OT, the necessary ranking for English of the four constraints listed previously and repeated below for clarity.

ONSET: *syllables must have onsets.*
NO CODA: *syllables must not have codas.*
***COMPLEX**: *syllables must not associate more than one C or V to a syllable position node.*
FAITH: *Every segment of the input has a correspondent in the output.*

If the known characteristics of English syllable structure are considered, then it is fairly easy to show that FAITH must dominate all of the other constraints. First, English does allow onsetless syllables. The word *a*, [ə], is a syllable composed of only a single vowel and since English speakers do not insert an initial consonant, they must disobey ONSET. Thus, FAITH must be ranked above ONSET as shown in Table 5.3.

TABLE 5.3
The Ranking of FAITH and ONSET in Adult English

	/ə/	FAITH	ONSET
☞	ə		*
	tə	*!	

Second, as was discussed previously, English does allow syllables to have codas. The word *puck*, [pʌk] contains a coda and since English speakers do not omit it, they must disobey NO CODA. Thus, FAITH must be ranked above NO CODA as shown in Table 5.4.

TABLE 5.4
The Ranking of FAITH and NO CODA in Adult English

	/pʌk/	FAITH	NO CODA
☞	pʌk		*
	pʌ	*!	

Third, English does allow syllables to have consonant clusters. The word *spark*, [spark], has initial and final consonant clusters and since adult English speakers produce the clusters, they must disobey *COMPLEX. Thus, FAITH must be ranked above *COMPLEX as shown in Table 5.5.

TABLE 5.5
The Ranking of FAITH and *COMPLEX in Adult English

	/spark/	FAITH	*COMPLEX
☞	spark		**
	park	*!	*

Thus, the following ranking has been established for English FAITH >> ONSET, NO CODA, *COMPLEX. In fact, despite the fact that the last three constraints are not ranked with respect to each other, this ranking is sufficient for English. This is because the parts of the output evaluated by ONSET and NO CODA will never be the same and also because English violates both in favor of strict adherence to FAITH, so there is no case that might require the ranking of one over the other.[2] Similarly, there is no case in English which might require the ranking of *COMPLEX over either of the other two constraints.

Summary

Hopefully, the preceding discussion has led to a clearer understanding of Optimality Theory. However, it may not yet be clear why OT is a relevant framework for a grammatical account of the cluster reduction data in this thesis. The logic here lies in the fact that the substance of structural constraints in OT stems from linguistic universals. As was mentioned earlier, all of the previous structural constraints conspire to define the

[2] The two are necessarily separable, however, because some language's restrictions on onsets and codas are different. E.g., when FAITH is ranked *between* ONSET and NO CODA the grammar requires that all syllables have onsets, but it does not require that all syllables be coda-less. This means that it is better to violate FAITH in order to satisfy ONSET (i.e., insert an onset if a syllable does not have one or delete the onsetless vowel), but it is not better to violate FAITH to satisfy NO CODA (i.e., codas are permitted but only to prevent a FAITH violation). This describes general properties of a language such as Yawelmani (see Archangeli, to appear).

optimal, preferred, or most well-formed syllable, CV. One of the implications of the Sonority Hypothesis is that children model their early speech on similar linguistic universals. Thus, a theory that uses these universals (albeit to formally account for adult phonological phenomena) opens a promising window towards a successful grammatical account of the child language data presented here. Indeed, much recent work in child phonology successfully pursues this same goal guided by the similar observation that phonological universals can define a large part of children's initial productions, as well as the stages children go through in their development of an adult grammar (Bernhardt & Stemberger, 1995; Demuth, 1995; Gnanadesikan, 1995; Massar, 1996; Massar & Gerken, 1996). To this end, the next section will detail an account of the cluster reduction data in an Optimal Theoretic framework.

5.2.2 An OT Analysis of Cluster Reduction

It seems prudent at this point to reiterate the empirical issues that need to be addressed in the ensuing analysis. The two most important aspects to be accounted for in this theory are the overall omission of elements in children's cluster reductions (i.e., children reduce clusters to single segments) and the specific character of those omissions as defined by the Sonority Hypothesis (i.e., children reduce clusters to the least sonorous segment in onsets and to the most sonorous segment in codas).

Children's Reduction of Clusters to Single Segments: FAITH & *COMPLEX

The first point, the reduction of consonant clusters, is most logically considered in light of the constraints identified previously as FAITH and *COMPLEX. The effect of FAITH, which demands a one-to-one correspondence between elements in the input and elements in the output, is to prohibit phonological deletion or insertion. As was shown earlier, for adult speakers of English this constraint ranks highly as faithfulness to the input is almost always maintained.[3] For children, it is clear that the superordinancy of FAITH is readily sacrificed during the production of reduced forms. In the current case, children readily omit one of the consonants in a cluster, while adults produce both. This suggests that children rank FAITH below some other constraint that governs the complexity of utterances.

This leads to a discussion of the second constraint relevant to children's omissions, *COMPLEX. The effect of this constraint is to prohibit more than one consonant (or vowel) in any syllabic position. As a result, consonant clusters are prohibited. *COMPLEX, then, is a constraint that governs the complexity of speech sound sequences. It is also a constraint which children obey since children do reduce consonant clusters to single segments. Thus, it must be the case that when children reduce consonant clusters they are obeying *COMPLEX but violating FAITH. This logic indicates a ranking of the constraints for the child data as *COMPLEX >> FAITH, contrary to the adult ranking of FAITH over

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[3] This is true with adults speaking careful English, however in fast speech omissions do occur (e.g., *tomato* [t^həmeto] becomes [tmeto]). See Hammond (to appear) for an OT analysis of this type of omission.

*COMPLEX. Table 5.6 illustrates what the outcome of this ranking would be for an input like /snuf/, which was reduced to [suf] by subjects in the first experiment.

TABLE 5.6
*COMPLEX >> FAITH in Child Speech

		/snuf/	*COMPLEX	FAITH
	a.	snuf	*!	
☞	b.	suf		*
☞	c.	nuf		*
	d.	su		**!
	e.	nu		**!

There are three important facts brought out by the tableau above. First, this ranking of constraints correctly rules out the candidate in (a), the adult output, as the optimal output for the child. If *COMPLEX were not superordinate to FAITH, then (a) would be chosen as optimal as this candidate receives no other violations. Since children do, in fact, reduce consonant clusters, then (a) must be ruled out, as shown. Second, the competition among the remaining candidates in (b-e) is somewhat mediated by FAITH. The candidates in (d) and (e) are also declared non-optimal because, in both cases, two elements in the input are omitted in the output. This results in two violations each of FAITH for these candidates. These are fatal violations compared to those in (b) and (c), where only one violation each of FAITH is incurred (because only one element from the input is omitted in the output). Finally, this constraint ranking does not choose between candidates (b) and (c). Both are considered equally optimal under this ranking. Clearly, another constraint is needed that will adjudicate between [suf] and [nuf] as outputs for /snuf/, ultimately choosing [suf] as optimal. Such a constraint would address the specific character of children's cluster omissions as established in this thesis, such that the least sonorous consonant is produced in the reduction of onset clusters and the most sonorous consonant is produced in the reduction of coda clusters.

The Specific Character of Children's Cluster Omissions: The SONCON Constraint

Clearly, a constraint or set of constraints that reflects the Sonority Hypothesis must be incorporated into the ranking of the other constraints, *COMPLEX and FAITH. While Prince & Smolensky (1993) do, in fact, propose one way of incorporating sonority into a constraint hierarchy, it is unsatisfactory in the present case because it does not deal with the asymmetry between onsets and codas and their differing preferences for less sonorous and more sonorous consonants, respectively. Prince & Smolensky propose a Universal Margin Hierarchy which ranks individual consonants according to the "...basic assumption that the less sonorous an element is, the more harmonic it is as a margin..." (1993: p.129), where "a margin" is a coda or an onset. These constraints take the form of *M/C which can be restated as "do not associate some consonant C to a margin." Individual consonants are then ranked along a hierarchy, e.g. *M/n >> *M/s >> *M/t, which reflects a general preference for less sonorous consonants in the margin of a syllable (i.e., it is better to make the less sonorous [t] a margin than the more sonorous [s], and so on). In the case of the reduction of [stig] to [tig] such a ranking is successful, as shown in

Table 5.7, because with onsets it is true that least sonorous consonants are preferred (only the two relevant margin constraints are shown here).

TABLE 5.7
Margin Constraints and Onsets in Child Speech

		/stig/	*M/s	*M/t
☞	a.	tig		*
	b.	sig	*!	

Here, both candidates receive violations for associating the respective onset consonants with the margin of the syllable. However, because *M/s is ranked above *M/, the violation in (b) is the fatal one. This ranking has the effect of choosing the form with the least sonorous onset consonant as optimal (a), which is correct in this case. However, the Margin Hierarchy does not reflect the fact that within the class of consonants there is a distinction between those consonants that make optimal onsets (least sonorous consonants) and those consonants which make optimal codas (more sonorous consonants). Thus, if a reduction of a coda consonant cluster is considered, such as [dust] to [dus], the wrong results are obtained because coda consonants prefer to be more, not less, sonorous. This is shown in Table 5.8 with relevant constraints from the Margin Hierarchy (a 💣 indicates that the wrong form has been chosen as optimal).

TABLE 5.8
Margin Constraints and Codas in Child Speech

		/dust/	*M/s	*M/t
	a.	dus	*!	
💣	b.	dut		*

In this instance as well, both candidates incur violations of the respective margin constraints. However, because *M/s is ranked above *M/t (which was shown to be necessary for the onset case in Table 5.7), the violation in (a) is the fatal one. The effect here is exactly the same as in the tableau above: the form with the least sonorous consonant in the coda is selected as optimal (b). But this result is incorrect because in the case of codas, more sonorous consonants are considered optimal; children produce [dus] for [dust], and not [dut]. Thus, to correctly model the cluster reduction data, the constraints incorporating sonority must choose less sonorous consonants as optimal for onsets and more sonorous consonants as optimal for codas. The Margin Hierarchy as proposed in Prince & Smolensky (1993) is incapable of achieving this result and so cannot account for the full set of data.

One other OT analysis that does attempt to make this distinction is proposed in Gnanadesikan (1995). However, Gnanadesikan's account suffers from the same problem, albeit in a different way, as the previous one: it cannot capture the facts of coda cluster reduction. In this work, Gnanadesikan outlines a different type of Margin Hierarchy, referred to as the μ/Y Hierarchy, where μ/Y can be stated as "each Y must be parsed as a mora." This hierarchy also ranks consonants, (e.g. μ/m,n >> μ/f,s >> μ/p,t) but is instead based on the assumption

> ...that the preference for low sonority in onsets derives from the related preference for high sonority in moraic (non-onset) positions. If a segment is excluded from onset position on the grounds of sonority, it is because the segment is better parsed as moraic. (p.8)

Thus, these types of constraints will assess output violations when the relevant consonant is parsed into a nonmoraic position in the syllable. The effect of the hierarchy is to ensure that consonants lower in sonority are better associated with non-moraic (or onset) positions than consonants higher in sonority. As with the Universal Margin Hierarchy, the μ/Y Hierarchy achieves the correct results in the case of children's onset cluster reductions. Table 5.9 demonstrates this, again using the form /stig/ and only depicting the relevant constraints from the hierarchy.

TABLE 5.9
μ/Y Constraints and Onsets in Child Speech

		/stig/	μ/s	μ/t
☞	a.	tig		*
	b.	sig	*!	

Under this analysis, both candidates incur violations of the respective μ/Y constraints because in neither case are the consonants assigned to moraic positions in the syllable. However, because μ/s is ranked above μ/t the violation in (b) is the fatal one. In other words, as stated before, it is better to assign a consonant lower in sonority, [t], to a non-moraic position, than one higher in sonority, [s]. This effectively chooses the candidate with the least sonorous onset as optimal, which is correct in this case. Thus, the μ/Y Hierarchy makes good use of the non-moraic/moraic distinction between consonants in the onset versus consonants in the coda (i.e., coda consonants have moras and onset consonants do not) to achieve the correct outcome for onset cluster reduction. However, this hierarchy fails to account for the coda cluster reduction data because the moraic/nonmoraic distinction proves to be moot in an evaluation of two codas. Consider Table 5.10 which gives the two outputs in competition for the child's reduction of [dust] with the relevant μ/Y constraints listed also.

TABLE 5.10
μ/Y Constraints and Codas in Child Speech

		/dust/	μ/s	μ/t
☞	a.	dus		
☞	b.	dut		

Under this analysis, neither candidate incurs violations of the relevant μ/Y constraints because both consonants, being codas, have moras. In fact, each candidate *satisfies* the maxim "each Y must be parsed as a mora". Unlike with onsets, the ranking of the two constraints cannot choose between the two forms because no violations have been incurred. In sum, as was the case with the Universal Margin Hierarchy, the μ/Y Hierarchy fails to choose the optimal output in the case of coda cluster reductions. In the former instance the Universal Margin Hierarchy actually chooses the incorrect form, while in the latter case the μ/Y Hierarchy cannot choose between the two relevant outputs. This means that the two OT analyses to date that attempt to model the full effects of sonority with constraints are both incapable of accounting for the cluster reduction data in this dissertation. Neither account addresses the fact that more sonorous consonants are preferred in coda position nor the related fact that syllables prefer a certain sonority contour overall.[4]

Thus, a constraint is still needed that models the entire effect of the Sonority Hypothesis, which is to channel productions towards syllables exhibiting the most optimal sonority contour. I propose a constraint that will be referred to as SONCON (for sonority contour) which states that syllables must begin with a maximal rise in sonority and end with a minimal sonority descent. This defines the optimal syllable as "stop-vowel". How well any given output satisfies this constraint will be assessed by asking whether the output matches the optimal syllable, in which case there will be no violations, or whether it does not match, in which case violations will be incurred. These violations will be measured by comparing both the onset of the output syllable with the onset of the optimal syllable, and by comparing the coda of the output syllable with the coda of the optimal syllable (by definition, an optimal syllable has *no* coda). What is now needed is a system for measuring the well-formedness of output syllables along these lines as well as a specific way for assessing violations of this constraint. One way of doing this is to adapt work that assesses the well-formedness of clusters in syllables (Borowsky, 1986; Clements

[4] One solution to this problem is to establish another hierarchy which would be the reverse of the ones given above. That is, there could be two hierarchies, one for the right margin (or non-moraic position) and one for the left margin (or moraic position). The effect would be that sonorous consonants on the left margin would receive more violations than non-sonorous ones, and non-sonorous consonants on the right margin would receive more violations than sonorous ones (see D. Ohala, 1994). However, this type of solution would achieve the sonority contour effect only in a coincidental sense as the hierarchies are independent of each other and do not refer to the overall optimality of the syllable shape. Further, margin hierarchies like these assess violations on all consonants on a margin, but in fact an optimal sonority contour is characterized as having some consonant on the left margin, preferably a stop consonant. Thus, separate hierarchies like these would not capture the central point that the sonority contour is a property of whole syllables, and not some artifact of individual consonant hierarchies.

& Keyser, 1983; Selkirk, 1982; Steriade, 1982) to an assessment of the well-formedness of optimal syllables.

As mentioned in §2.3, the Sonority Sequencing Principle (SSP) has been used to partially define the cluster inventory of English. As was shown, nearly all onset and coda clusters adhere to this principle. However, some cluster types that adhere to the SSP nevertheless do not occur in the language, such as stop-fricative clusters (e.g. [tf-]). To account for the absence of a number of cluster types in the inventory, researchers have proposed that languages define a Minimal Sonority Distance (MSD) between consonants in a cluster such that all well-formed clusters in a language adhere to this distance, while ill-formed clusters violate it and so are impossible in that language (Selkirk, 1982; Steriade, 1982; Borowsky, 1986). The MSD for each language is calculated by making reference to intervals along the sonority scale, which is repeated in Figure 5.1 from Figure 2.1 (where '<' stands for 'are less sonorous than").

Stops < Fricatives < Nasals < Liquids < Glides < Vowels

Figure 5.1. The Sonority Hierarchy.

Adjacent positions in the Sonority Hierarchy are separated by one interval. For example, stops and fricatives are one interval apart, while stops and nasals are two intervals apart. The MSD for English as proposed in Borowksy (1986) is three intervals. This defines well-formed clusters in English as ones whose individual consonants are at least three intervals apart. Thus, stop-liquid clusters (e.g. [pl-], [pr-]) are well-formed in English because there are three intervals between liquids and stops on the sonority scale. Similarly, stop-glide clusters (e.g. [tw-], [kw-]) are well-formed in English because there are four intervals between stops and glides on the sonority scale. However, stop-fricative clusters (e.g. [pf-], [ps-]) are ill-formed because there is only one interval between stops and fricatives and this violates the MSD for English.[5] For each language, the well-formedness of clusters with respect to sonority is assessed by counting the number of intervals between consonants on the sonority scale and comparing this to the MSD for that language.

While this way of measuring the well-formedness of clusters has never been extended to whole syllables, it seems a logical step to do so and it provides a precedented solution to the need for a well-formedness measurement in the present context. To reiterate: a means of assessing violations of SONCON is required, where SONCON states that syllables must begin with a maximal rise in sonority and end with a minimal sonority descent and effectively compares both the onset of the output syllable with the onset of the optimal syllable and the coda of the output syllable with the coda of the optimal syllable. This can be achieved, to start just with the coda cases, by counting the number of intervals along the sonority scale (in a manner similar to the above) between the output coda and the optimal coda. The number of intervals between the different consonant types and the vowel are identified in Figure 5.2.

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[5]It may be obvious that this notion of Minimal Distance cannot alone account for all existing or non-existing clusters in English. For example, there are some fricative-stop clusters, such as [st-] and [sp-], which are allowed and some stop-glide clusters, such as [bw-] and [pw-], which are not. The reader is

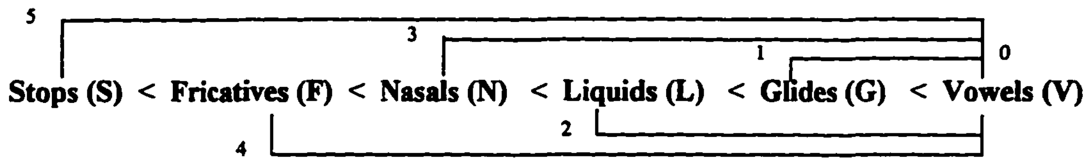

Figure 5.2. The sonority scale with number of intervals between vowel and consonant type marked.

Recall that the optimal syllable has no coda at all. Thus, output syllables that have no coda are well-formed with respect to SONCON and should therefore receive no violations (i.e., there are zero intervals). An output syllable that does have a coda will not be well-formed with respect to SONCON and will incur violations which can be assessed by counting the number of intervals between the optimal syllable coda (i.e. no coda, or a vowel-final syllable) and any coda in the output. For example, an output syllable containing a glide in the coda would incur one violation of the constraint because there is one interval between the vowel and the glide on the sonority scale (see Figure 5.2). Similarly, an output syllable containing a liquid in the coda would incur two violations of SONCON because there are two intervals between the vowel and the glide. Table 5.11 shows each possible vowel-consonant combination from the scale above listed with the number of violations each sequence would incur: the number of violations corresponds directly to the number of intervals.

TABLE 5.11
Coda Violations of SONCON

Coda Type	V	VG	VL	VN	VF	VS
# Violations		*	**	***	****	*****

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referred to §2.3 for a discussion of other types of restrictions that are used to account for the cluster inventory of English.

In this way, SONCON can assess the relative optimality of codas in output syllables by assessing fewer (or no) violations for those output syllables that maintain a minimal sonority descent.

In a similar manner, SONCON can assess onsets in the output, however the number of violations must be reversed since sequences that make an optimal onset (stop-vowel) make the worst coda (vowel-stop). Table 5.12 shows each possible consonant-vowel combination with the number of violations each sequence would incur.

TABLE 5.12
Onset Violations of SONCON

Onset Type	SV	FV	NV	LV	GV	V
# Violations		*	**	***	****	*****

In this case, a stop-vowel syllable receives no violation because this sequence provides the maximal rise in sonority required by SONCON. Other types of consonants in the onset will incur an increasing number of violations, depending on how many intervals there are between the optimal stop consonant and the relevant consonant in the output. In this way, SONCON achieves a measurement of the well-formedness of optimal syllables with respect to both onsets and codas as is required for an analysis of children's cluster reductions.

To give a specific example of how this constraint works, consider the violations incurred by the output forms [suf] and [nuf] as reductions for the form /snuf/, as shown in Table 5.13.

TABLE 5.13
The Effects of SONCON for the Form /snuf/

		/snuf/	SONCON Onset Violations	SONCON Coda Violations
☞	a.	suf	*	****
	b.	nuf	**!	****
	c.	uf	**!***	****

The first thing to note in the table above is that SONCON does correctly identify candidate (a), [suf], as the optimal reduction of /snuf/. The CV contour in (a) is FV. Because a fricative onset is one interval away from the optimal stop onset, the output onset in this form receives only one violation of SONCON (see Table 5.12). However, the CV contour in (b), NV, receives two violations of SONCON because a nasal onset is two intervals away from the optimal stop onset. This form, then, receives an extra and fatal violation in comparison to the form in (a), and so is ruled out. Finally, a form with no onset at all (c), fatally receives five violations of SONCON because vowels are five intervals away from the optimal stop onset.

The second thing to note in the table is that both forms receive independent violations of SONCON for the codas contained in the output syllables. The VC contour in both forms is the same, VF, which receives four violations of the constraint because a fricative coda is four intervals away from the optimal, no coda syllable contour (see Table 5.11). Because both forms have the same coda, these violations are moot (although when coda cluster reductions are examined later, these will play a role). However, this brings up an important point about SONCON: this constraint has two independent branches. As illustrated in the table above, one branch assesses the well-formedness of the CV (or onset) contour and the other branch assesses the well-formedness of the VC (or coda) contour. This suggests that a more accurate characterization of SONCON is as a family of constraints (like FAITH) which is composed of separate constraints that reflect these two branches and that together conspire to assess an output syllable's optimal sonority contour. Henceforth, SONCON will be separated into SONCON_O (for SONCON ONSET) and SONCON_C (for SONCON CODA). These constraints, like ONSET and NO CODA, are unrankable with respect to each other because they assess violations on different parts of the output (see §5.2.1).

Recasting SONCON in this manner does not affect the evaluation of the forms in Table 5.13, but it may be significant if one considers that this formulation of the constraint could obviate the need for ONSET and NO CODA. In earlier discussion it was pointed out that ONSET and NO CODA together describe the optimal syllable, CV. The SONCON constraints also derive this effect but further specify the optimal syllable as SV (stop-vowel). Additionally, the SONCON constraints can assess the overall well-formedness of output syllables with respect to their segmental content, which ONSET and NO CODA cannot do. The SONCON constraints also derive the effects of ONSET and NO CODA in a more principled fashion by explicitly making reference to the optimal sonority contour, whereas ONSET and NO CODA are more stipulative. Thus, it may be the case that ONSET and NO CODA should be replaced with SONCON_O and SONCON_C. In order to ascertain whether or not this is truly the case, the SONCON constraints would need to be examined in light of other data formerly accounted for by ONSET and NO CODA. Because this question defines a large area of research, I pose it here as a possible consequence of the analysis of cluster reduction, but leave the answer for future study.

To summarize so far, this section has justified the need for a new family of constraints in OT, in response to the cluster reduction data, that addresses syllables' preferences for an optimal sonority contour. The constraints proposed are SONCON_O and SONCON_C which together state that syllables must begin with a maximal rise in sonority and end with a minimal sonority descent.

The Complete Analysis

It is now appropriate to return to the overall analysis of children's cluster reductions. At the last point in the discussion it was clear that another constraint was needed in addition to *COMPLEX and FAITH. The ranking established for these two constraints was *COMPLEX >> FAITH. But this could not adjudicate between the forms [suf] and [nuf] as outputs for /snuf/. This stage in the analysis was illustrated by Table 5.6, which is repeated here as Table 5.14.

TABLE 5.14
*COMPLEX >> FAITH in Child Speech

		/snuf/	*COMPLEX	FAITH
	a.	snuf	*!	
☞	b.	suf		*
☞	c.	nuf		*
	d.	su		**!
	e.	nu		**!

The introduction of the SONCON constraints into this ranking now completes the analysis of children's reduction of /snuf/. Consider the effect of the ranking *COMPLEX >> FAITH >> SONCON$_O$ and SONCON$_C$, as shown in Table 5.15 below.

TABLE 5.15
*COMPLEX >> FAITH >> SONCON$_O$, SONCON$_C$

		/snuf/	*COMPLEX	FAITH	SONCON$_O$	SONCON$_C$
	a.	snuf	*!		(***)	****
☞	b.	suf		*	*	****
	c.	nuf		*	**!	****
	d.	su		**!	*	
	e.	nu		**!	**	

With this ranking of the constraints, the optimal output [suf], is correctly chosen as children's reduction of /snuf/. As was remarked on previously, *COMPLEX is needed to eliminate candidate (a)[6], while FAITH eliminates candidates (d) and (e). Because candidates (b) and (c) receive the same number of violations of FAITH, the decision of which candidate is optimal lies in the jurisdiction of the constraint ranked next in the hierarchy. This is the newly added SONCON$_O$ which eliminates candidate (c). (The NV onset contour incurs two violations of SONCON$_O$ as compared to the FV onset contour in [suf] which

[6] Ultimately, SONCON$_O$ would also evaluate the optimality of syllables containing multi-consonant onset clusters. There are presumably a variety of alternatives for assessing these CCV or VCC violations. The one I use here assigns violations to a C^2C^1V sequence by assessing the C^1V sequence concurrently with the C^2C^1 sequence. If "goodness" of onset is still regulated by the number of intervening intervals along the sonority scale, then the sequence [snu] in [snuf] incurs two violations for the NV sequence [nu], and one violation for the FN sequence [sn]. Thus, the entire CCV sequence incurs three violations of SONCON$_O$. A similar argument could be made for SONCON$_C$ with respect to multi-consonant coda clusters. In general, this raises the question of whether (and how) one wants to make judgements about the relative optimality of multi-consonant clusters; e.g.., whether [snu] is a more optimal sequence than [flu] or [blu].

only incurs one violation.) In this way, the correct reduction of /snuf/ is chosen, candidate (b).

An Excursus on Reranking

While the constraint ranking shown above (*COMPLEX >> FAITH >> SONCON$_O$, SONCON$_C$) provides similarly effective analyses of the other initial cluster reductions attested in this dissertation, it is important to note that other permutations of the constraint ranking achieve the wrong results for these data. Consider the effect of ranking FAITH *below* the other constraints, as shown in Table 5.16.

TABLE 5.16
*COMPLEX >> SONCON$_O$, SONCON$_C$ >> FAITH

		/snuf/	*COMPLEX	SONCON$_O$	SONCON$_C$	FAITH
	a.	snuf	*!	***	****	
	b.	suf		*	****!	*
☞	c.	su		*		**
	d.	nuf		**!	****	*
	e.	nu		**!		**

In this case, the incorrect form [su] is chosen, candidate (c). As before, *COMPLEX rules out candidate (a). However, candidates (d) and (e) in this tableau are ruled out, not by FAITH but by SONCON$_O$. The NV contour in both these forms incurs two violations of SONCON$_O$ as compared with only one violation incurred for the FV contour in candidates (b) and (c). The candidate in (b), however, receives four additional violations of SONCON$_C$

because of the non-optimal VF contour in the coda. This rules out [suf], which is actually the correct candidate, and instead chooses the incorrect [su].

However, it is important to note that the ranking of *COMPLEX with respect to the SONCON constraints needn't be strict; even if *COMPLEX were ranked below the SONCON constraints, [su] would still be selected as the optimal output, as shown in Table 5.17.

TABLE 5.17
SONCON$_O$, SONCON$_C$ >> *COMPLEX >> FAITH

	/snuf/	SONCON$_O$	SONCON$_C$	*COMPLEX	FAITH
a.	snuf	(***) [7]	****!	*	
b.	suf	*	****!		*
☞ c.	su	*			**
d.	nuf	**!	****		*
e.	nu	**!			**

Thus, the only critical ranking for achieving this output (i.e. [su]) is the demotion of FAITH to the bottom of the hierarchy: *COMPLEX, SONCON >> FAITH.

Although the preceding constraint ranking is not correct for the cluster reductions presented in this dissertation, it is nevertheless an important one. This is because children do, at an earlier stage of production, produce forms that lack final consonants altogether (Leopold, 1939-49; Velten, 1943; Smith, 1973; Ingram, 1974; Menn, 1978; among others). That is, children's initial productions are often composed of CV syllables only. In

[7] Because of the uncertainty involved in calculating violations of SONCON in consonant clusters (cf. fn 6), I am not relying on SONCON$_O$ to rule out candidate (a). In general, one would assume that the FNV onset contour in [snuf] must be at least the same or worse as the FV contour in [su]. In the event that these two onset contours are considered equally optimal, then [snuf] can be ruled out by SONCON$_C$ (by virtue of the non-optimal VF coda contour).

fact, strict adherence to the SONCON constraints predicts the existence of such an earlier stage, since the most optimal syllable has, in fact, no coda. This suggests that different permutations of the constraint ranking can model different stages in children's phonological development. The constraint ranking just shown (*COMPLEX, SONCON >> FAITH) is relevant at an earlier stage, while the ranking in Table 5.15 (*COMPLEX >> FAITH >> SONCON$_O$, SONCON$_C$) is the correct ranking for the developmental stage highlighted in this work.

Consider now the effect of ranking FAITH *above* the other constraints, as shown in Table 5.18. (Here again, *COMPLEX and the SONCON constraints needn't be strictly ranked).

TABLE 5.18
FAITH >> SONCON$_O$, SONCON$_C$, *COMPLEX

		/snuf/	FAITH	SONCON$_O$	SONCON$_C$	*COMPLEX
☞	a.	snuf		***	****	*
	b.	suf	*!	*	****	
	c.	nuf	*!	**	****	
	d.	su	**!	*		
	e.	nu	**!	**		

This ranking of the constraints selects candidate (a) as the optimal output. All other candidates are ruled out by FAITH. While this is an incorrect ranking for the child cluster reduction data because it does not choose [suf], it nevertheless models another stage in the child's development. This stage is the final stage, as candidate (a) is the optimal adult output for the input /snuf/.

Thus, the three different permutations of the constraints reviewed so far have predicted three stages in the child's phonological development. First, the ranking *COMPLEX, SONCON$_O$, SONCON$_C$ >> FAITH predicted an attested, early stage where children's productions are composed of CV syllables. Second, the ranking *COMPLEX >> FAITH >> SONCON$_O$, SONCON$_C$ forecast a later stage of production where children's utterances conform to the most optimal CVC syllable possible, as attested in children's cluster reductions. Finally, the ranking FAITH >> SONCON$_O$, SONCON$_C$, *COMPLEX depicted a final stage of production where children's forms essentially match the adult output. When all three rankings are considered together, as shown below, it is clear that these rankings are derived from the steady advancement of FAITH up the constraint hierarchy.

CV:	*COMPLEX, SONCON$_O$, SONCON$_C$ >> **FAITH**
Cluster Reduction:	*COMPLEX >> **FAITH** >> SONCON$_O$, SONCON$_C$
Adult Output:	**FAITH** >> SONCON$_O$, SONCON$_C$, *COMPLEX

In this way, children's developmental stages can be seen as a reflection of their increasing faithfulness to the input. This raises the question of whether other possible rankings of FAITH among these constraints also depict attested stages in children's phonological development. However, because the main goal of this section as a whole is to present an OT-based grammatical account of the cluster reduction data, no further permutations of the constraints above will be considered. It is clear, though, that different rankings will predict many different and very specific stages in children's acquisition of syllables.

Assessing the accuracy of these predictions is another area for future research which will test the strength of the proposed SONCON constraints and which may ultimately suggest more specific formulations of them.

Further Cluster Reduction Examples in OT

Having ultimately suggested a constraint ranking that should account for all the cluster reduction data (*COMPLEX >> FAITH >> SONCON_{O}, SONCON_{C}), it is now important to illustrate the effectiveness of this ranking with an example of each of the different cluster types that underwent cluster reduction in the experiments presented in Chapters Three and Four. These examples are given in Tables 5.19 (showing initial clusters) and 5.20 (showing final clusters).

TABLE 5.19
An Account of Children's Cluster Reductions: Initial Clusters

			*COMPLEX	FAITH	SONCON$_O$	SONCON$_C$
		/snuf/				
	a.	snuf	*!		***	****
☞	b.	suf		*	*	****
	c.	nuf		*	**!	****
	d.	su		**!		
	e.	nu		**!		
		/skub/				
	a.	skub	*!		*	*****
☞	b.	kub		*		*****
	c.	sub		*	*!	*****
	d.	ku		**!		
	e.	su		**!	*	
		/bwɪv/				
	a.	bwɪv	*!		********	****
☞	b.	bɪv		*		****
	c.	wɪv		*	****!	****
	d.	bɪ		**!		
	e.	wɪ		**!	****	
		/fwim/				
	a.	fwim	*!		*******	**
☞	b.	fim		*	*	**
	c.	wim		*	****!	**
	d.	fi		**!	*	
	e.	wi		**!	****	

TABLE 5.20
An Account of Children's Cluster Reductions: Final Clusters

			*COMPLEX	FAITH	SONCON$_O$	SONCON$_C$
		/fisk/				
	a.	fisk	*!		*	*****
☞	b.	fis		*	*	****
	c.	fik		*	*	*****!
	d.	ɪs		**!	*****	****
	e.	ɪk		**!	*****	*****
		/mɛpf/				
	a.	mɛpf	*!		**	******
☞	b.	mɛf		*	**	****
	c.	mɛp		*	**	*****!
	d.	ɛf		**!	*****	****
	e.	ɛp		**!	*****	*****

The most important point to note in these two tables is that the constraint ranking established earlier does, in fact, correctly select the optimal reduction (candidate (b) in all cases) as the child's true phonological output for each example.

Summary

This section has provided an Optimality Theoretic account of the cluster reduction data established in this dissertation. Under this account, children's sonority-based cluster reductions result from the interaction of three constraints in the grammar: *COMPLEX, FAITH, and SONCON, ranked in that order. The effect of this constraint ranking is to channel children's cluster reductions towards the syllable containing the most optimal sonority contour for forms of the shape CVC. In addition, different permutations in the ranking of these constraints achieve different developmental stages, one of these being the adult ranking.

It is important to point out that this analysis is based on the notion that phonological constraints in the grammar, not physical constraints on the articulators, are responsible for children's reductions. In this type of grammatical model, articulatory factors are excluded from any role in children's early speech; instead, the assumption is that a specific interaction of constraints (as defined above) shapes children's utterances. Clearly, this particular constraint-based model is capable of accounting for the phenomenon of cluster reduction in child phonology. What is not yet clear is whether or not this Optimality Theoretic model has other properties which might recommend it as a larger framework of phonological acquisition. One way of determining this is to return to the four issues discussed in §5.1, and to evaluate the model's success or failure at accounting for these significant concerns.

5.3 Conclusion: OT and Issues in Phonological Acquisition

To review, there were four issues identified earlier as ones which must be addressed by any responsible theory of child phonology. These were: i) the existence of significant parallels between child language and adult cross-linguistic patterns, ii) the existence and the effect of variability in child data, (iii) the existence of numerous stages of development in child phonology, and (iv) the existence of asymmetries between children's production and comprehension of utterances. The following sections will address each of these topics in turn in light of the OT analysis of cluster reduction just presented.

5.3.1 OT, Child Phonology, and Linguistic Universals

As stated earlier, the main goal of the Optimality Theoretic analysis given in the previous section was to specifically address the existence of parallels between child data and linguistic universals. In fact, the relationship between child phonology and adult cross-linguistic patterns follows from the structure of Optimality Theory itself. As stated earlier, in OT a grammar is composed of a set of ranked constraints governing the well-formedness of utterances. The substance of a subset of these constraints (the structural constraints, like *COMPLEX and SONCON) is derived from linguistic universals such that together they define the preferred phonological patterns found across languages (e.g, *COMPLEX and SONCON define the optimal syllable, CV). As shown in the excursus on reranking, these are the very cross-linguistic patterns that children emulate in their initial productions (e.g., at an early stage, children produce only CV syllables). Because the constraints defining these patterns are the ones that dominate in the child's constraint ranking (cf. Tables 5.16-5.17), the emergence of the same patterns in child speech as in adult cross-linguistic data is, in fact, expected under an OT account. Given this, the parallels found between child phonology and linguistic universals come as no surprise in an OT approach and are, in fact, overtly acknowledged: an OT approach formally relates child phonology and linguistic universals.

5.3.2 OT and Variability

A second issue on which to evaluate the OT model stems from the substantial amount of variability that occurs in children's productions (sometimes of the same forms) within a five minute, one hour, or daily period. The problem as phrased earlier was how to account for the significant but general patterns that exist in child phonology at the same time as allowing for the inconsistency also present. In an Optimality Theoretic model of phonological acquisition, this kind of variability could be handled by a reranking of the constraints. For example, a child that produces the form [snuf] as [suf] has a constraint ranking of *COMPLEX >> FAITH >> SONCON$_O$, SONCON$_C$ (see Table 5.15). To later produce the form correctly as [snuf], the child reranks the constraints as FAITH >> SONCON$_O$, SONCON$_C$, *COMPLEX (see Table 5.18). Thus, a child that produces these two forms alongside one another, at one time ranks the constraint FAITH between the other constraints, and at another time ranks FAITH above the other constraints.

Clearly, a reranking mechanism might be added to the theory to account for the variability in children's productions. However, it is not clear whether such a mechanism is desirable. Since children do actually produce the same form in different ways within very short time spans, this would imply that children are constantly reranking constraints in the grammar. Consider also that reduced forms produced by excessively stressed, fatigued, or inebriated adults are similar to forms produced by children (Reiss and Hale, 1996). To account for these similarities, a model such as OT would necessarily claim that the variability exhibited by inebriated adults, for example, is also the result of constraint reranking. However, in this case (as with the others) the more likely explanation is that variability results from limitations on the performance system.

These facts raise doubts as to the plausibility of reranking as a means of accounting for variability in child speech. Thus, it seems that while an OT model is quite capable of explaining general patterns found in child phonology, it is less capable of satisfactorily accounting for the variability also present in child data.

5.3.3 OT and Phasal Development

Another issue that was raised earlier was how to account for phasal development in child phonology. Recall that there are two important points to consider with respect to this problem. The first is how to account for what causes phasal change and the second is how to account for the nature of the stages themselves.

As previously mentioned, different permutations of the constraint rankings can portray attested developmental stages in the acquisition of syllable structure (see Tables 5.15-5.18). This can be considered an attribute of an OT-based account in that such a model is capable of predicting in a highly specific way what the various stages of development are. However, it relies on the assumption that constraints can be reranked.

In fact, some notion of reranking is necessary under an OT approach. As mentioned earlier, under an OT account the set of constraints in the grammar is innate, but the ranking of the constraints is not. Given that the different permutations of these constraint rankings define any number of the world's languages, some reordering of constraints must take place in order for the child to learn the correct ranking for his/her language. If such a mechanism were not available, then the ranking for each language would also have to be innate. Thus, the reranking of constraints that describes children's phasal development can be seen as a reflection of the learning process the child goes through to converge on the correct constraint ranking for his/her language. Thus, there is a substantive difference between the kind of constant constraint reranking necessary to account for variability and the necessary kind of reranking exhibited in phasal development.

However, even given the necessity for this type of constraint reranking, there is still the question of why children rerank the constraints in the first place; some principled reason must be offered to account for this phenomenon. Explanations of this problem generally rely on children's gradual realization that their grammar is "wrong", forcing them to reevaluate, and presumably adjust, their constraint rankings. However, such explanations are not only vague but are belied by children's advanced comprehension capabilities; i.e., children know that the forms they produce are not the same as the target forms they are trying to achieve.

5.3.4 OT and Comprehension~Production Asymmetries

This raises another, final issue through which to evaluate the current OT model: the comprehension-production asymmetry exhibited by children. The crux of the problem is how to simultaneously account for children's advanced comprehension skills and their limited productions under one grammar. That is, the grammar must be responsible at one and the same time for children's attested recognition of adult target forms but their inability to produce these forms correctly. While this dilemma has generally been troublesome for grammatical accounts such as the one presented here, it seems possible that an OT approach could successfully address this asymmetry.

At its simplest, the task children must undertake in comprehension is to somehow pair what a speaker says with any number of representations in their own lexicon that might meet the general characteristics of the utterance heard and to select the correct lexical representation/utterance pairing regardless of how they might themselves produce that utterance. As we have seen, OT is a model that through a particular set of ranked constraints assesses the well-formedness of any input/output pair and selects the output that best satisfies the constraint ranking as the most optimal production. It seems highly likely that this same mechanism could also be utilized to assess the best fit between representation/utterance pairings during comprehension. In addition, it seems possible to achieve this using the same constraint hierarchy that accounts for children's limited productions.[8]

Consider the following example. Suppose the child has a constraint ranking like the one used to account for the cluster reduction data: *COMPLEX >> FAITH >> SONCON$_O$, SONCON$_C$. A child hears the word *ski* [ski] (a word that his/her own constraint ranking would produce as [ki], shown later in Table 5.22) and initiates a search for representations

[8] I am grateful to Diana Archangeli for pointing out the following possibilities. The reader is also referred to Ito, Mester, & Padgett's (1995) paper on Lexicon Optimization.

in his/her lexicon which might match that utterance. Suppose the child finds (at least) two likely representations /ski/ and /ki/, both of which are words and which might correspond to the utterance the child heard. The child then has two different representation/utterance pairings, /ski/-[ski] and /ki/-[ski], and must decide which of the two representations best agrees with the utterance (s)he heard.

At this point, the child's constraint ranking (as shown above) comes into play to determine which pairing exhibits the best possible fit given the utterance [ski]. In fact, assuming that the most optimal representation/utterance pairing is the one that incurs the least number of violations at any given point, the child's constraint ranking (as is) correctly identifies /ski/-[ski] as the best pairing, as shown in Table 5.21. As dictated by the OT framework, violations of constraints are still assessed on the outputs. However, unlike in production where the outputs vary with respect to some input, in comprehension the output (i.e. the utterance the child heard) remains constant while the underlying representations with which the utterance is paired vary. Thus, candidate (a) pairs the output [ski] with a representation /ski/, while candidate (b) pairs the same output with a different representation /ki/.

TABLE 5.21
Representation/Utterance Pairings for an Utterance [ski]

			*COMPLEX	FAITH	SONCON$_O$	SONCON$_C$
☞	a.	/ski/-[ski]	*		*	
	b.	/ki/-[ski]	*	*!	*	

Under the child's constraint ranking, both candidates receive violations of the highest ranked constraint, *COMPLEX, because of the initial consonant cluster in the output. The selection of the optimal pairing is then left up to the next constraint in the hierarchy, FAITH. In this case, the two candidates do receive differential treatment (and so the SONCON constraints become irrelevant). FAITH assesses no violations on the pairing in candidate (a) because there is the required one-to-one correspondence between the representation /ski/ and the utterance [ski]. However, the pairing in candidate (b) does receive a violation of FAITH because an item in the output (i.e. the [s] in [ski]) does not correspond with any item contained in its partner representation (i.e. /ki/). Thus, the pairing in candidate (b) is ruled out in favor of that in (a). In this way, the child correctly associates the utterance (s)he heard, [ski], with the best corresponding lexical representation /ski/. This occurs despite the fact that the child's own production of /ski/ is [ki], as shown in Table 5.22.

TABLE 5.22
A Child's Production of /ski/

		/ski/	*COMPLEX	FAITH	SONCON$_O$	SONCON$_C$
	a.	[ski]	*!		*	
☞	b.	[ki]		*		
	c.	[si]		*	*!	

As we have seen with numerous other examples (cf. §5.2.2), at this stage of production utterances are channeled to reflect the most optimal syllable possible. The constraint ranking, which now in production assesses violations on varying outputs, selects the reduced [ki] as the optimal production.

Now consider the outcome if the child *hears* the utterance [ki], which in this case could be an adult's imitation of the child's own production of the word [ski]. During comprehension, the child might also pair [ki] with the same representations as (s)he paired with [ski] earlier, namely /ski/ and /ki/. In this case, though, the pairings would be /ski/-[ki] and /ki/-[ki]. As Table 5.23 shows, the child's grammar would not select /ski/-[ki] as the optimal pairing, but would instead select /ki/-[ki] (again, the SONCON constraints are irrelevant).

TABLE 5.23
Representation/Utterance Pairings for an Utterance [ki]

			*COMPLEX	FAITH	SONCON$_O$	SONCON$_C$
	a.	/ski/-[ki]		*!		
☞	b.	/ki/-[ki]				

In this case, neither candidate pairing receives a violation of the highest ranked constraint, *COMPLEX, because there are no consonant clusters in the output [ki]. However, the pairing in candidate (a) receives a violation of the next-ranked constraint, FAITH, because the output utterance does not maintain a one-to-one correspondence with its partner representation (i.e., while there is an [s] in the underlying representation, there is not an [s] in the utterance). The pairing in candidate (b), however, receives no violations of FAITH because the one-to-one correspondence is maintained. Therefore, /ki/-[ki] is chosen as the optimal representation/utterance pairing.

In sum, then, while the child may pronounce /ski/ as [ki] (Table 5.22), (s)he would reject /ski/ as the optimal underlying representation for an adult utterance of [ki]. Instead, the child would identify an adult utterance of [ki] as corresponding with the underlying representation /ki/ (Table 5.23) and would identify an adult utterance of [ski] as corresponding with the underlying representation /ski/ (Table 5.21).

Thus, this exercise (while highly speculative) has raised the possiblity that an OT framework may be capable of addressing the asymmetries between children's comprehension and production: by manipulating what is assessed by the constraint ranking, input/outputs in production and representation/utterance pairings in comprehension, a single OT grammar can account at one and the same time for children's rich comprehension but poor production.

Of course, this issue is much more complicated in scope than is considered here and, to be fully responsible, would require further study. In fact the proposal independently developed here is in essence the same as that in Smolensky (1996); the reader is referred to that work for a fuller discussion, including an example from syntax. (See also Tesar & Smolensky, 1993, 1996; Pulleyblank & Turkel, 1995; Reiss & Hale, 1996).

5.3.5 Summary

The previous discussion has revealed that an Optimality Theoretic approach has qualities both desirable and undesirable in a model of phonological acquisition. Table 5.24 summarizes this evaluation with respect to each of the four issues raised by the research presented in this dissertation.

TABLE 5.24
An Evaluation of an OT Model

Issue	Evaluation
1. Cross-Linguistic~Child Language Parallels	*Advantage*: existence of parallels is predicted by the model.
2. Variability	*Disadvantage*: solutions require constant reranking of constraints.
3. Phasal Development	*Advantage*: stages are accurately and specifically predicted by minimal reranking of the constraints (which is necessary for the child to converge on the correct ranking for his/her language). *Disadvantage*: there is no specific explanation for what causes the child to rerank constraints.
4. Comprehension~Production Asymmetries	*Advantage*: a single constraint ranking accounts for children's production and comprehension of utterances by assessing violations on input and outputs (production) vs. representation/ utterance pairings (comprehension).

From this table, it can be seen that the only disadvantages of an OT model of phonological acquisition stem from its inability to satisfactorily account for variability in child data and for children's phasal reranking of constraints. In fact, these issues are problematic for any grammatical model, be it rule-, parameter-, or constraint-based and are not specific to an OT approach. The question that remains, then, is how best to account for variability in any theory of child phonology.

It was suggested during the earlier discussion of variability (§5.3.2) that the fluctuations regularly exhibited in children's productions more likely stem from limitations on the performance system rather than from any mechanism in the formal grammar. If this view is adopted, then such variability can be explained by the fact that children do not initially possess fully developed articulators nor do they initially possess the complex motor skills required to master them. Further, the child's mastery of his/her articulators is somewhat better or worse depending on any number of other motor or cognitive factors that might intervene in the process (Reiss and Hale, 1996). Along similar lines, the stages evident in early speech can be seen to reflect a maturation of the articulators and other abilities which make it possible for the child to produce more and more complex utterances. By making recourse to these types of performance factors, the variability found in children's productions can be seen to result from both immature motor skills and underdeveloped cognitive skills. Such factors are not part of the grammar but are part of the performance system and seem also to influence children's productions. This suggests that perhaps the best theory of phonological acquisition is one that takes into account the effects of various performance factors on children's productions while also providing a formal model of the grammar.

In sum, the contribution of the discussion in the previous section has been to provide much insight on how some critical issues in phonological acquisition might be resolved. By examining an OT approach to phonological acquisition, we have seen how a model can build in resolutions to the issues of: i) parallels between child language and linguistic universals, (ii) phasal development (in part), and (iii) comprehension-production asymmetries. The one issue that remains problematic is that of variability in child data which may best be explained by considering that limitations on the child's performance system also affect children's early speech.

CHAPTER SIX: CONCLUSION

"Where ya gonna seep tonight?" B, 2 year old.

6. Introduction

The goals of this dissertation as stated in Chapter One were: (i) to provide a substantive, sonority-based account of cluster reduction that focuses on the similarities between child data and linguistic universals, (ii) to outline a specific relationship based on these universals between child and adult language, and (iii) to identify properties critical to a successful theory of phonological acquisition as brought out by this work, using an Optimality Theoretic analysis of the cluster reduction data as a vehicle to consider how best to account for these issues in a formal model of acquisition.

In this chapter, I review precisely how these objectives have been achieved. First, I summarize the general claims of the Sonority Hypothesis as well as the combined empirical results of the two experiments. In the process, I show how this sonority-based theory of cluster reduction exactly accounts for the data presented. Second, I summarize the Optimality Theoretic analysis of the cluster reduction data that identifies the relationship between child and adult phonology as one of constraint reranking. Third, I summarize the larger implications of this research for models of phonological acquisition in general and for the OT model detailed earlier. Lastly, I detail the specific and general implications of the research presented in this thesis as well as identify directions for future inquiry.

6.1 Summary of the Sonority Hypothesis

The Sonority Hypothesis presented in this dissertation is a theory of cluster reduction in child phonology that capitalizes on the similarities between the content and shape of syllables produced in child speech and the preferred shape and content of syllables cross-linguistically. This hypothesis suggests that, in fact, children's cluster reductions target the production of the most preferred syllable type possible given the composition of the target cluster. In other words, during cluster reduction children choose to produce whichever of the two consonants in the cluster will create the most optimal syllable type.

As was shown in Chapter Two, the definition of an optimal syllable is achieved by making reference to the linguistic notion of sonority. Sonority was first established as an explanation for the specific patterns of consonant sequencing found in syllables across languages. Researchers noted that if consonants were ranked with respect to their sonority (their loudness with respect to each other), then it could be shown that consonants low in sonority were preferred at syllable edges and consonants high in sonority were preferred adjacent to the syllable peak (i.e. the vowel). Further, it was noted that sequences of syllables exhibit consistent cycles of rising and falling sonority. From these observations, it was suggested that an optimal syllable contains a maximal rise in sonority at the beginning and a minimal, or no, descent in sonority at the end (Clements, 1990). In this way, syllables of all types can be assessed for their relative optimality. For example, *ta* is a more optimal syllable than *sa* because stops (like [t]) are less sonorous than fricatives (like [s]), and so provide a maximal rise in sonority from the consonant to the vowel. The necessity for this particular characterization of an optimal syllable is affirmed by other linguistic phenomena, such as reduplication in Sanskrit and Greek (also shown in Chapter Two).

Assuming this definition of an optimal syllable, the Sonority Hypothesis then makes specific predictions about the kinds of cluster reductions children should produce. These are that initial consonant clusters should reduce to the consonant that creates a syllable with a maximal rise in sonority, and that final consonant clusters should reduce to the consonant that creates the syllable with a minimal sonority descent. For example, an initial consonant cluster composed of [s] followed by [t] (as in *stick*) should reduce to [t] (as in [tɪk]), because [t] is less sonorous then [s] and creates a maximal sonority rise. However, the same cluster in final position (as in *fist*) should reduce to the [s] (as in [fɪs]), because [s] is more sonorous than [t] and creates a minimal sonority descent.

6.2 Summary of Experimental Results

Chapters Three and Four of the thesis presented two experiments designed to test the Sonority Hypothesis against an account of cluster reduction based on articulatory ease, the latter explanation being the focus of previous analyses of the data (as discussed in Chapter One and in §2.6). The first experiment elicited cluster reductions from children who were asked to repeat nonsense words of the shape CCVC or CVCC. In this study the adjacent consonants comprised legal English clusters. In the second experiment, children were asked to repeat nonsense words of the same shape, but the adjacent consonants comprised illegal English clusters.[1] Table 6.1 summarizes the findings of both of these studies by indicating the patterns of cluster reduction obtained for the individual cluster types. Included alongside the actual results are the patterns predicted by both the Sonority Hypothesis (SH) and the Articulatory Ease Hypothesis (AEH). E1 and E2 in the table below stand for Experiment One and Experiment Two, respectively.

TABLE 6.1
Results of Experiments One and Two

Clusters from E1	**Actual Pattern**	**SH Pattern**	**AEH Pattern**
initial fricative-stop	stops > fricative	stops > fricative	stops = fricatives
initial fricative-nasal	fricatives > nasals	fricatives > nasals	nasals > fricatives
final fricative-stop	fricatives > stops	fricatives > stops	fricatives = stops
Clusters from E2	**Actual Pattern**	**SH Pattern**	**AEH Pattern**
initial stop-glide	stops > glides	stops > glides	glides > stops
initial fricative-glide	fricatives > glides	fricatives > glides	fricatives = glides
final fricative-stop	fricatives > stops	fricatives > stops	fricatives = stops
final stop-fricative	fricatives > stops	fricatives > stops	fricatives = stops

[1] However, as was shown in Chapter Four, only half of the original cluster types were candidates for cluster reduction. Only these items from Experiment Two are now discussed (cf. §4.3.2 for an explanation of the other cluster types).

These results show that the patterns of cluster reduction attested in both experiments are identical to those predicted by the SH. This correspondence is emphasized by the shading of the two relevant columns in the table. In addition, the patterns predicted by the AEH clearly stand out in opposition to the actual findings of these studies. Consequently, it can be concluded that children's cluster reductions are driven by considerations of the sonority of the individual consonants that make up the target cluster. As suggested by the Sonority Hypothesis, children reduce consonant clusters in such a way that the most optimal syllable possible is produced, given the composition of the cluster itself.

6.3 Summary of OT Analysis

One section of Chapter Five of this thesis placed the resulting cluster reduction data in relation to an overall theory of child phonology. This was accomplished by making recourse to the constraint-based framework of Optimality Theory (Prince & Smolensky, 1993). This theory is appropriately geared towards the optimization of utterances and is uniquely capable of providing a unified model of both the child and the adult cluster reduction data. In this framework, adult phonology consists of a set of violable, ranked constraints that define the shapes of utterances in languages. This means that children and adults must operate under a set of identical constraints. If this is true, then the reason that children's utterances initially differ from adults cannot be attributable to differences in the substance of the constraints, but instead must be a result of the reordering of the same constraints.

This relationship between the child and the adult data was reified in the specific analysis of cluster reduction give in §5.2. In this section, it was shown that previous implementations of sonority in Optimality Theory are incapable of accounting for any data involving clusters. In addition it was shown that implementations of sonority outside of the OT framework are also not capable of accounting for the data. Therefore, the analysis presented is one that proposes a new, but necessary, family of constraints that specifies the optimal shapes of syllables in utterances. In addition, the analysis of cluster reduction subsumes two constraints already well-established in the literature. These constraints are reviewed below, with the two familiar constraints listed first.

***COMPLEX:** *no more than one C or V may associate to any syllable position node (no consonant clusters allowed).*

FAITH: *every segment of the input has a correspondent in the output (no phonological deletion or insertion).*

SONCON$_O$: *syllables must begin with a maximal rise in sonority; and*
SONCON$_O$: *syllables must end with a minimal sonority descent. (stop-vowel is the optimal syllable);*

Violations of *COMPLEX and FAITH are straightforwardly assessed with one violation for a syllable node containing more than one C or V and one violation for each segment of the input with no correspondent in the output, respectively. Violations of SONCON are assessed in a more complicated fashion by examining how well the output matches the optimal syllable as defined previously. The number of violations incurred corresponds to the number of intervals along the sonority scale between the consonant under consideration and the optimal point (which differs depending on whether the consonant is before or after the vowel).

The constraint ranking necessary to achieve the cluster reduction data, as argued previously, is exemplified below in Table 6.2. Also included in this table is the ranking that would provide the optimal adult response.

TABLE 6.2
Constraint Rankings for Child and Adult Outputs

	CHILD RANKING					
		/snuf/	*COMPLEX	FAITH	SONCON$_O$	SONCON$_C$
	a.	snuf	*!		***	****
☞	b.	suf		*	*	****
	c.	nuf		*	**!	****
	d.	su		**!	*	
	e.	nu		**!	**	
	ADULT RANKING					
		/snuf/	FAITH	SONCON$_O$	SONCON$_C$	*COMPLEX
☞	a.	snuf		***	****	*
	b.	suf	*!	*	****	
	c.	nuf	*!	**	****	
	d.	su	**!	*		
	e.	nu	**!	**		

In this way, the child data and the adult data are differentiated by a constraint ranking that specifies either the presence or absence of cluster reduction. The crucial constraint in this case is *COMPLEX, which is superordinate in the child's ranking, but is subordinate in the adult ranking. The child's ranking of these constraints can be seen to represent a less marked stage in the developing phonology (i.e., utterances adhere more closely to the basic and preferred syllable shapes, cross-linguistically) while the adult system trades a more marked phonology for one that accurately corresponds to the input.

6.4 Summary of Issues in Phonological Acquisition

Chapter Five of this dissertation also identified a number of issues brought out by the research that are relevant to any theory of phonological acquisition, and subsequently examined how best to account for them in light of one possible model (the constraint-based OT model summarized previously). These issues are encapsulated in Table 6.3 below.

TABLE 6.3
Issues in Phonological Acquisition

1. Significant parallels between child phonology and linguistic universals
2. Variability in child data
3. Phasal development in child phonology
4. Comprehension-production asymmetries in child language

The importance of the first issue, parallels between child phonology and linguistic universals, has been substantiated in detail by the work presented here. The Sonority Hypothesis is based on the notion that a specific relationship obtains between children's early productions and cross-linguistically attested patterns in adult language. The experiments conducted then confirmed that this relationship does exist: children reduce consonant clusters in such a way that the resulting syllables adhere as closely as possible to cross-linguistically preferred syllable shapes as defined by sonority. Thus, a theory of phonological acquisition must make some account of this relationship as these parallels are clearly not coincidental.

The experimental paradigm employed in this dissertation raised a second important issue in phonological acquisition: the presence of variability in child data. Because the results of these investigations are probabilistic (i.e., children do not always respond the same 100% of the time), the hypothesis presented accounts for general, but significant, patterns found in the data but not absolutes. This means that some children did not respond according to the Sonority Hypothesis, but instead responded with the correct pronunciation of the cluster or some other deviation therein. Additionally, the same child's responses often varied quite freely (e.g. a full cluster vs. a reduced cluster) from token to token. Given the prevalence of this type of variability, it is incumbent upon a theory of phonological acquisition to be able to account both for the general patterns and the variability in child phonology.

A third issue raised by this research arose from the fact that the data is representative of only one stage in children's phonological development. Cluster reduction is exhibited by children in a relatively narrow window and is preceded and followed by other stages in the acquisition of syllables (e.g. the CV stage and the adult output stage, respectively). In some manner, a theory of child phonology must address the nature of the stages through which a child progresses as well as what causes the child to progress from stage to stage.

A fourth and final issue that was brought out by the research was the difference between comprehension and production skills in children. That is, children are able to understand more complex utterances than they can produce. Additionally, they can differentiate between the two (i.e., children recognize that their own productions do not match adult target forms). The problem that a theory of phonological acquisition must resolve here is how to account for children's rich comprehension of the adult language and their limited productions of the same.

Further discussion in Chapter Five then examined, through an OT model of acquisition, how best to account for these concerns. In this section it was shown how one model could build in specific resolutions to the majority of these issues. By using constraints that reflect linguistic universals and which are then dominant in the child's grammar, the parallels between child language and linguistic universals are not only accounted for, but are expected under an OT approach. Additionally, by a minimal reranking of the constraints in the child's grammar, specific stages in children's phonological development are predicted to occur. It was also shown that by assessing violations of constraints on input and outputs in production but on representation/ utterance pairings in comprehension, a single OT grammar can account for children's advanced comprehension but limited production. Finally, while moving us towards a more comprehensive model of phonological acquisition in these ways, the evaluation of the OT account also highlighted the fact that variability and the cause of phasal progression remain problematic not just for an OT model but for any grammatical theory of acquisition. In response to these residual concerns, it was suggested that resolution of these issues might more likely lie within the domain of the performance system rather than within the formal grammar.

6.5 Implications and Future Research

The work presented in this thesis speaks to a number of different issues in child phonology and phonology in general. I separate these into the specific consequences of the analysis provided here and the more general consequences of this approach to child phonology. Also discussed are areas for future investigation subsequent to the various points raised below.

6.5.1 Specific Implications

At the very least, this research has shown that previous accounts of cluster reduction based on articulatory ease lack explanatory power. Any theory of child speech based on such considerations needs to be much more explicit than is presently the case. In addition, insofar as any such theory suggests itself (cf. the AEH in §2.6), the studies presented here refute it as a viable explanation of cluster reduction. This aspect of the thesis emphasizes the need for more explicit theories of articulatory ease in order for there to be truly competitive accounts of the cluster reduction phenomenon.[2]

More importantly, however, this work has provided a definitive and viable account of cluster reduction based on sonority. The relevance of sonority to this process in child speech is affirmed by the success of the Sonority Hypothesis in accounting for the data in the two experiments presented (which, in themselves, contribute to present knowledge of cluster reduction patterns). This particular analysis shows that children's decisions regarding cluster reduction are subject to fine-grained considerations of consonant quality, position of the cluster in the word, and the composition of the target cluster. All of these are addressed in a theory of reduction based on sonority.

The claims of the Sonority Hypothesis could be additionally strengthened by further investigations of children's reductions. As was discussed earlier, the experiments on initial and final cluster reduction conducted in this dissertation are comprised of an exhaustive list of the types of clusters available for reduction for children in this age group. However, cluster reduction also occurs word medially. In this case, the predictions of the SH would become more complicated because the stress of the syllables would play a role in determining the affiliation of the medial cluster in the target word. For example, a fricative-stop cluster in a word with primary stress on the second syllable would be syllabified as part of that second syllable (e.g., *mesquite* [məskit] would be syllabified as

[2] Conceivably, the Sonority Hypothesis itself could be cast as a theory of articulatory ease. For example, the Sonority Hypothesis could be construed as a particular type of articulatory account which assesses the relative ease or difficulty of different types of syllables. In this case, sonority would correspond to particular articulatory or acoustic parameters (as some have argued, cf. Chapter Two).

me-squite [mə-skit]). In this case, the SH would predict a reduction of the [sk] cluster to [k] (i.e. [mə-kit]). However, for fricative-stop clusters like the one in *basket*, the predictions of the SH are less clear. Words like these have primary stress on the first syllable and the association of the two medial consonants is less certain (i.e. *bas-ket*, *bas-sket*, or *ba-sket*). In this case, the uncertain composition of the syllables in the word makes it difficult to ascertain what the predictions of the SH would be. Clearly, more complicated considerations would be involved in an investigation of reductions in medial-clusters. However, the effectiveness of the Sonority Hypothesis in accounting for all types of cluster reduction would be solidified by such a study.

Along slightly different lines, the sonority-based research presented in this thesis suggests that other child phonological phenomena might be as successfully explained by making recourse to sonority. For example, from the definition of an optimal syllable, it follows that children's initial utterances would be of the shape CV. This is already known to be true as evidenced by studies of final consonant deletion in child speech. It would also follow that the preferred consonant in these CV utterances would be a stop consonant, such that stops are substituted for consonants of other types in early speech. A further prediction is that in CVC utterances children would prefer stops to fricatives as the initial consonant, but fricatives to stops as the final consonants. An investigation of these predictions and others like them would ascertain whether sonority is limited in relevance to cluster reduction or whether it extends to other phenomena in early speech.

Finally, there are specific implications of the Optimality Theoretic analysis presented for both adult and child language. One possible consequence of the analysis, as raised earlier, was that the SONCON constraints may obviate the need for the previously proposed constraints ONSET and NO CODA (Prince & Smolensky, 1993). The effect of these latter two constraints is obtained by the SONCON constraints which also define the optimal syllable shape, CV. However, the SONCON constraints further define the optimal syllable as stop-vowel and can additionally assess the overall well-formedness of the output syllables with respect to their segmental content. Furthermore, these effects are derived in a principled fashion by the SONCON constraints which make reference to the optimal sonority contour, while ONSET and NO CODA are basically stipulative. Overall, however, to determine whether these latter constraints are no longer needed, it is necessary to investigate whether the newly proposed SONCON constraints can account for the same data formerly addressed by ONSET and NO CODA. In addition, it is also important to ascertain whether all the various rerankings of the SONCON constraints with respect to other constraints, like *COMPLEX and FAITH, predict attested languages and/or stages in child language development. Earlier exercises showed that different permutations of the ranking of these constraints did predict attested stages in phonological acquisition. However, other such permutations are possible and need to be investigated in order to determine the validity of the SONCON constraints and whether or not these constraints need to be refined in any way.

6.5.2 General Implications

Perhaps the most significant issue addressed by this thesis is brought out by the use of the term "optimal". In Optimality Theory, whether an utterance is optimal is dependent on how well the utterance in question satisfies the relevant constraint ranking of a particular phenomenon. These constraints, when taken as superordinate, specify utterance shapes consistent with patterns of preferred utterance shapes cross-linguistically. Therefore, optimality is determined by comparing any particular utterance to some previously defined "default" shapes specified as optimal in the grammar. In other words, insofar as languages universally prefer to have utterances of certain shapes and insofar as some languages deviate from these shapes, then optimality is a measure of that deviation. What is not clear in this framework is precisely what makes these utterance shapes optimal and not others. For example, what are the factors that contribute to making "ta" an optimal utterance?

This is essentially the question I asked when investigating cluster reduction in children's speech: what makes "ta" a better reduction of "sta" than "sa"? This thesis has suggested that sonority provides a means for classifying what is meant by optimal. This classification was shown to be already necessary for explanations of other phonological phenomena, thus providing explanatory power of a sort not achieved in formulations of articulatory ease. With this sonority-based definition it was shown that children's cluster reductions resulted in the production of the most optimal syllable given the components of the cluster under consideration.

However, there are two important points to note about this definition of optimality. The first is that sonority is admittedly a much more complex quality of speech sounds than was assumed in this dissertation. If, in fact, the sonority of a speech sound is subject to the particulars of a variety of factors (e.g. the interplay of a number of distinctive features or acoustic properties or both), then in order to precisely arrive at a definition of "optimal", further research would need to be done. This is not study that is limited to investigations of child phonology, as a precise definition of optimality is clearly relevant to adult phonological theory as well. In addition, for phonology as a whole (i.e. in other phonological domains), the relevance of sonority is not assured. For example, suppose it is the case that stress systems in languages prefer trochees (alternating patterns of stressed syllables followed by unstressed syllables) to iambs (alternating patterns of unstressed syllables followed by stressed syllables) (Hammond, 1992). In this case, sonority has no bearing on the relative optimality of trochees to iambs, and so the issue of what is optimal in language is much larger than what can be defined by sonority.

Notwithstanding these broader implications of this research as addressed above, this dissertation has ultimately provided a set of explanatory principles that allow for the consideration of these more complex questions on a firmer empirical footing. More specifically, this dissertation has provided an explicit account of the cluster reduction facts as well as a clearer understanding of the relationship between this phenomenon and sonority in adult phonology, and between child and adult phonology in general.

APPENDIX A

LIST OF STIMULI FOR EXPERIMENT ONE, ENGLISH CLUSTERS

Stimuli with Word-Initial Clusters

1.	[skub]	5.	[staud]	9.	[sneb]
2.	[sked]	6.	[stig]	10.	[snuf]
3.	[skoyv]	7.	[stoyn]	11.	[snaud]
4.	[skof]	8.	[stɔn]	12.	[snig]

Stimuli with Word-Final Clusters

13.	[vɛsk]	17.	[lost]	21.	[darp]	25.	[nalk]
14.	[fisk]	18.	[dust]	22.	[mərp]	26.	[valk]
15.	[gask]	19.	[zæst]	23.	[zorp]	27.	[kɛlk]
16.	[nʌsk]	20.	[jest]	24.	[narp]	28.	[dælk]

29.	[fimp]
30.	[dɛmp]
31.	[gamp]
32.	[vʌmp]

APPENDIX B

LIST OF STIMULI FOR EXPERIMENT ONE, NON-ENGLISH CLUSTERS

Stimuli with Word-Initial Clusters

1.	[tfuk]	5.	[tmæv]	9.	[bwæz]	13.	[fnoyv]
2.	[tfoyd]	6.	[tmof]	10.	[bwav]	14.	[fnɛb]
3.	[tfɛg]	7.	[tmaud]	11.	[bwʌk]	15.	[fnug]
4.	[tfayb]	8.	[tmɔn]	12.	[bwij]	16.	[fnij]

17.	[fwʌg]	21.	[mwɛk]
18.	[fwæb]	22.	[mwag]
19.	[fwɪv]	23.	[mwʌj]
20.	[fwim]	24.	[mwib]

Stimuli with Word-Final Clusters

25.	[mɛpf]	29.	[gɪfp]
26.	[væpf]	30.	[nɛfp]
27.	[zʌpf]	31.	[dafp]
28.	[bʊpf]	32.	[bæfp]

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