FORMAL AND COGNITIVE RESTRICTIONS ON VOWEL HARMONY

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ABSTRACT

Vowel harmony, a phonological process whereby adjacent vowels share values of a phonological feature, has raised important challenges for generative phonology, particularly Optimality Theory (OT) (Prince and Smolensky, 1993/2004), a theory of linguistic typology in which output forms are computed in parallel from an infinite candidate set. The parallel nature of computations in OT, as well as the unconstrained candidate set for possible outputs poses challenges for a theory of vowel harmony, which applies in a local fashion, such that vowels share the same feature value as their nearest neighbor. Particularly, standard theories of vowel harmony in OT predict the existence of pathological vowel harmony processes that are unconstrained by locality, producing patterns that are never found in natural language. Building on the work of Turbidity Theory (Goldrick, 2001), this dissertation proposes Turbid Spreading, a theory of representations for harmony that provides a solution to the 'myopia' generalization in OT. Representations for features are both rich as well as constrained, making it possible to account for several aspects of vowel harmony (e.g., non-participating vowels and epenthetic vowels) without over-predicting. Evidence for the completeness of the predicted typology is provided using computational methods (i.e., finite-state machines). The cognitive bases for the typological restrictions on vowel harmony typology are verified in a series of 12 experiments using the artificial grammar learning paradigm in adults. In these experiments, English speakers are exposed to mini versions of vowel harmony languages, followed by a forced-choice comprehension test. This test contains novel items as well as items from the training set. In particular, several novel test items include novel representations (e.g., novel vowels), which have been specifically held out from training to test. This 'poverty of the stimulus' method (Wilson, 2006) makes it possible to test learners' bi inferences towards ambiguous stimuli. The results of these experiments suggest that learners' biases conform to the cross-linguistic typology of harmony languages. Learners are biased to learn harmony patterns that are frequently occurring and phonetically natural, but biased against rare or non-existing patterns. These findings support the hypothesis that typological restrictions are grounded in learning biases.

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Chapter 1: Introduction

1.1 The Need for an Integrated Approach to Linguistics

As part of the field of cognitive science, linguistics has continued to make important contributions to related disciplines, such as psychology, computer science and philosophy. In recent years, interest in the interdisciplinary nature of the study of language has reached new heights. Because language is a biological, cultural and cognitive function of human nature, it is only natural that language should be studied from a variety of viewpoints.

In order to truly understand the nature of human language, there must be a theory that can explain the typological distribution of linguistic forms in terms of both formal and cognitive factors. This type of theory can only emerge from an integrated approach to the study of language, making use of a wide range of tools and methodologies. Each researcher working on language much make use of the tools of their neighbors; experiments influence theory and vice versa, for example.

This dissertation is an attempt at integrating theoretical, computational and experimental approaches to the study of language focusing on a single phenomenon: vowel harmony. Vowel harmony is defined as a phonological process that occurs in languages that require adjacent vowels to share a particular feature value (e.g., back, round, tense). For example, in a round vowel harmony language (as in Turkish), if the first vowel is round, the following vowels must also be round. The distribution of harmony in the world's language is extremely rich. Vowel harmony can be found in a wide range of different language families and locations, including: Romance varieties as in Pasiego Montañes of Spain which displays a morphologically conditioned ATR harmony, as well as a height harmony pattern (Dyck, 1995; J.-I. Hualde, 1989; J. I. Hualde, 1992; McCarthy, 1984; Ralph J. Penny, 1969, 1970; R. J. Penny, 1972; Piccard, 2001; Vago, 1988), African languages, such as height harmony in Bantu (Clements, 1991; Hyman, 1999; Riggle, 1999) and ATR harmonies in several Nilotic languages such as Datooga and Lango (Andersen, 1999a, 1999b; Bakovic, 2005c; Creider & Rottland, 1997; Dimmendaal, 2002; Jacobson, 1980; Rottland, 1983), Native American languages such as Nez Perce ATR harmony (Aoki, 1968; Hall & Hall, 1980; Kiparsky, 1973), and several others, including Finnish, Hungarian and Turkish harmony systems.

There are many reasons to incorporate vowel harmony in an integrated approach to the study of language. First, vowel harmony is a robust linguistic phenomenon that involves linguistic primitives such as features and natural classes. Second, the typology of vowel harmony is rich, giving much room for studying theoretical and cognitive reasons for the typological restrictions on vowel harmony (Nevins, 2004). Third, vowel harmony has always posed an interesting problem for theoreticians and experimentalists alike, making it feasible to incorporate both experimental and theoretical techniques for studying the same phenomenon. Previous interest in vowel stems from the fact that vowel harmony is one of the best cases of a truly all-pervasive phonological phenomenon, assimilation, of particular interest because of its unbounded potential, making it highly relevant to yet another all-pervasive linguistic issue, locality.

The work presented in this dissertation is an attempt to allow for mutual influence of experimental results on theoretical formulations, and theoretical considerations on experimental design. While the majority of the interaction between experimental and theoretical work uses theoretical linguistics to inform experimental linguistics, the results of the experimental work have great potential be applied back to theoretical work, particularly in understanding the nature of directional constraints for vowel harmony. The experimental results can also help inform theories of constraint formation as well as theories of the initial state for constraints on vowel harmony. Because the bulk of the feedback comes from theory to experimental work, the dissertation is organized such that theoretical approaches to vowel harmony are presented separately from the experimental results.

1.2 Optimality Theory and Vowel Harmony

The theoretical framework adopted in this dissertation is Optimality Theory (OT) (Prince & Smolensky, 1993/2004)[1]. In this framework, a universal set of constraints on phonological forms is ranked via strict domination. There are two classes of constraints: faithfulness and markedness. Faithfulness constraints govern the relationship between the input to the grammar (underlying form) and the output. Faithfulness constraints demand that the output form varies as little as possible from the input form or underlying form. Markedness constraints govern the output representation, and demand that output forms be as least marked as possible. The theory of markedness states that certain segments and phonological processes enhance perceptual salience, are articulatorily easy to pronounce, easiest to learn and most likely to be spared in aphasics (Jakobson, 1968). A representation is 'marked' if violates these principles on phonetic naturalness and structural simplicity. Markedness constraints and faithfulness constraints interact such that faithfulness works to keep marked structures in the output, while markedness works

[1] I assume that readers are familiar with Optimality Theory. For a brief yet comprehensive introduction, see (Smolensky, Legendre, & Tesar, 2006).

to eliminate such structures. Their interaction is governed through ranking: high ranked markedness constraints yield unmarked outputs, while high ranked faithfulness yield the possibility for both marked and unmarked structure. OT is a theory of typology because each possible ranking of a constraint predicts a different language. Possible output structures (candidates) are evaluated in parallel fashion with respect to these constraints in terms of the ranking. For any given input, an infinite candidate set is evaluated in terms of which candidate violates the fewest high-ranked constraints. The optimal candidate is what surfaces in the language.

The idea that grammar involves constraint interaction, evaluated in parallel has made it possible to integrate theories of generative grammar into theories of learning (Boersma, 1999; Boersma & Hayes, 2001; Boersma & Levelt, 1999; Fikkert, 2005; Hayes, 2001; Legendre, Hagstrom, Vainikka, & Todorova, 2002; Pater & Tessier, 2003; Tesar & Smolensky, 1998; Tessier, 2007, submitted) and processing (Stevenson & Smolensky, 2006). It has also given new insights into the debate over which aspects of language are innate, and how such innate mechanisms might be instantiated in the learner (Hayes, 1997, 2001; Hayes & Steriade, 2004; Soderstrom, Mathis, & Smolensky, 2006; Wilson, 2006). Within phonology proper, Optimality Theory has lead to advances in the field, providing an account of inventory effects, conspiracies, and rule-ordering paradoxes (Alderete, 1999; Bakovic, 2005b, 2006a, 2006b; Ito & Mester, 1995; Kiparsky, 2000; Legendre, 2001; McCarthy & Prince, 1995; Prince & Smolensky, 1993/2004).

The fact that OT employs global, parallel evaluation of possible outputs has many advantages. For example, in the English past-tense, epenthesis applies if assimilation would create two identical consonants (e.g., heat, heated, *heatt, *heatd) (Bakovic, 2005a). This is a very cumbersome (if not impossible) rule to produce: apply epenthesis if and only if assimilation creates identical vowels. However, OT accounts for this pattern naturally– all possible candidates are evaluated in parallel, allowing for epenthesis to be contingent on the output of assimilation.

While Optimality Theory allows for elegant analyses of phonological processes, the global nature of constraint evaluation can also lead to incorrect predictions (corresponding to unattested languages). This is most clearly exemplified in the typological predictions of vowel harmony. Standard analyses of vowel harmony tend to over-predict. Specifically, these analyses predict languages that violate the 'myopia' property of vowel harmony. This generalization states that while vowel harmony is long-distance, it applies in a local fashion (vowels agree with their nearest neighbor in feature value) that cannot see beyond the locus of spreading. These standard analyses of vowel harmony predict non-local interactions in that are never found in natural languages.

Because OT is a theory of typology, the analyst must take seriously how the interaction of proposed constraints will affect language typology. The fact that OT can generate multiple repairs for a particular markedness constraint, many of which are unattested (termed the 'too many solutions' problem (Blumenfeld, 2006; Steriade, 2000, 2001; Wilson, 2000, 2001)) is one instance where OT grammars over-generate. This is particularly problematic for vowel harmony. Wilson (2003a) has demonstrated that constraints governing vowel harmony have been particularly problematic in predicting unattested languages. This problem stems from the fact that while vowel harmony constraints must have scope over an entire lexical item, the spreading process of vowel harmony applies iteratively from one segment to the next (Kiparsky, 1981). Wilson (2003a) calls vowel harmony 'myopic' because iterative spreading has no look-ahead power, but while standard OT can handle the global scope of vowel harmony, it has much more difficulty in accounting for the directional, iterative nature of vowel harmony. This is problematic because OT, as a theory of universal linguistic typologies, cannot afford to predict wildly unattested languages.

While OT analysts must ensure that the theory of languages does not overgenerate, all researchers must ensure that they capture all of the typological facts. Because vowel harmony has a rich typology of attested patterns and restrictions, this is no easy task. Vowel harmony creates strong statistical tendencies for all vowels to share the same feature value, however, there are often systematic failures for vowels to share the same feature value. Many vowel harmony languages have restrictions on which vowels may trigger or undergo vowel harmony. A harmony trigger is a vowel that induces spreading, the source of vowel harmony. A harmony undergoer is a vowel that undergoes spreading by taking on the feature of a harmony trigger.

There are two main types of restrictions on vowel harmony triggers. The first type is characterized by the nature of the trigger itself. For example, in some round harmony systems, only high vowels are allowed to spread the feature [ROUND] (Kaun, 1995, 2004). The other type of restriction depends on whether the trigger and the undergoer for harmony match. In other round harmony systems, any vowel may spread its [ROUND] feature, but only if the vowel it spreads to shares its feature value for height (J. Cole & Trigo, 1988; Kaun, 1995, 2004). In these restricted systems, a high vowel may spread to another high vowel, and a mid vowel may spread to another mid vowel, but a mid vowel cannot spread to a high vowel and vice versa.

There are also two main types of restrictions on harmony undergoers. The first type is based on the segmental inventory of the language. In vowel harmony languages, there is a correspondence between the harmonic sets (e.g., [+HIGH] vowels and [–HIGH] vowels). However, if one [+HIGH] vowel does not have a [–HIGH] counterpart in the segmental inventory, that vowel cannot undergo harmony. In this situation, two things may occur: transparency or opacity. In transparency, the spreading vowel's feature continues to spread through the transparent vowel onto vowels that follow the transparent vowel. In opacity, the non-undergoer blocks spreading, but can spread its own feature value to neighboring vowels. The second type of restriction on undergoers concerns the particular feature value of the undergoer; only vowels with a specific feature value may undergo the harmony process. For example, in many height harmony languages, only front vowels are allowed to undergo harmony. A back vowel will not participate in the height harmony rule.

These restrictions are not accidental. Cross-linguistically, there are some vowels that are more likely to have harmonic counterparts in the inventory than others, and there are some vowels that are more likely to match the featural description for undergoers than others. It is not enough to be able to account for a particular feature value undergoing or failing to undergo harmony. Rather, one must provide an explanation for why harmony fails to apply, and this explanation must match the typological findings for vowel harmony.

In Optimality Theory, these types of typological restrictions can be formalized in terms of learning biases: biases on the initial state of the learner. For example, if constraints are universal (either learned or innately specified), then some constraints might have initial privilege over others. If constraints are learned, these constraints may be learned faster than others. The explanation for why vowel harmony has the restrictions it does may come from biases in learning.

In this dissertation, I provide evidence that many of the restrictions that are found in vowel harmony typologies can be explained in terms of learning biases. The work presented here provides the basis for a fully integrated theory of vowel harmony, one that takes into account both learning biases and typological restrictions. The methodology for uncovering learning biases that is used here is an artificial grammar learning paradigm in adults. In this paradigm, adult participants are exposed to a small portion of a 'made-up' language. In this case, the artificial language has vowel harmony. Following brief exposure to the language, participants are tested on their knowledge of the language. Specifically, they are given novel items, not heard at training. By giving participants these novel items, it is possible to test whether the participants learned a pattern beyond mere memorization of the training items. By testing items that are outside the training space, it is possible to get a glimpse at the representations that learners infer from the training set. In the experiments presented here, we employ the Poverty of the Stimulus method (Wilson, 2006). The idea is that if learners are exposed to only a small set of the possible language, (e.g., height harmony applying to front vowels only) the learner will have to infer how the missing elements (e.g., back vowels) must behave without any training. If the learner is biased towards a particular type of vowel harmony process (e.g., against back vowels undergoing harmony), this will be reflected in the learner's performance to these novel items. Generalization to novel structures (vowels, affixes, etc.) outside the training space reflects a learning bias towards a pattern that includes these novel items. Failure to generalize to these novel items reflects a learning bias for a pattern that does not include these items. By testing whether learners are able to generalize to novel items can we can better understand whether the typological restrictions on vowel harmony can be represented in terms of a learning bias.

Besides typological restrictions on vowel harmony (such as markedness of undergoers and triggers of harmony), there are other typological factors that shape vowel harmony that have important theoretical consequences. One such issue is the role of directionality in harmony processes. The majority of vowel harmony processes are stem-outward, often applying from left to right, but there are cases of bi-directional harmony. One question that arises is whether there is a 'default' direction in harmony processes, or whether directionality in harmony can be analyzed as an artifact of the morphology. For example, many languages (such as Turkish) appear to have rightwards spreading of harmony, but this harmony process always applies from a stem to a suffix. Because Turkish has no prefixes, it is impossible to tell whether Turkish harmony is left-to-right or stem-outward, and would affect prefixes if there were prefixes in the language.

A second issue in the typology of vowel harmony systems concerns the putatively pathological predictions from OT analyses. A pathological prediction in OT is a grammar generated by an OT analysis that is unattested, and can never occur in natural language. The question that can be addressed experimentally is whether these "pathological" languages never occur in the typology of vowel harmony as an accident or because of cognitive biases on the structure of phonological processes.

The dissertation provides a discussion of myopic patterns in vowel harmony, as well as an overview of proposed solutions, including their problems and prospects. I propose a novel, representational look at the problem, providing the beginnings of a solution, using turbid representations, termed Turbid Spreading, which I will now introduce.

1.3 An Integrated Theory of Vowel Harmony

This dissertation presents an integrated theory of vowel harmony based on experimental and theoretical results. In this section, I present the overall result of this endeavor. The Turbid Spreading Theory of vowel harmony involves enriched representation in which each iteration of spreading is present in the representation, as in autosegmental representations of spreading (Clements, 1976). The source of spreading is distinguished from undergoers as the representation, just as in headed feature domains theory (Smolensky, 2006) and span theory (McCarthy, 2004; O'Keefe, 2007).

Optimizations of representations for spreading are conducted within Optimality Theory. Each potential representation for spreading is a candidate produced by GEN. Constraints on GEN, (restrictions on possible output candidates) which lead to a restricted candidate set, are describable in terms of finite-state machines. Constraints found in EVAL (restrictions on how constraints are evaluated) must be converted into finite-state machines as well. The finite-state requirement posed here ensures that all constraints and representations in the candidate set are formally and precisely specified. It also ensures the most parsimonious computation possible. If a candidate/constraint can be formalized in terms of a finite-state machine, it suggests that the proposed system is both formally tractable as well as learnable. Further, by describing the entire system in terms of finite-state machines, it is possible to employ extremely valuable computational machinery.

Each representation for spreading contains three levels: the underlying form, the phonological form, and the surface form. The underlying and surface forms can be found in standard OT representations of phonological forms. The intermediate level, the projection/phonological level, represents the hidden (turbid), abstract level at which phonological processes occur. For each vowel segment, there is a representation of these three levels. All vowels must be projected by a licenser that can come from the underlying form (representing no phonological change), the surface form (representing phonetic change), and a neighboring segment on the phonological level (representing spreading).

In the example below, each segment is specified for the binary feature value of the harmonic feature (e.g., Back, ATR, etc.). Projection relations are represented with arrows, spreading with horizontal arrows (a subset of the projection relations).

(1) Representations in Vowel Harmony

/ + + – / ↓	Underlying Form
+ → + → +	Projection/ Phonological Level
[+ + +]	Surface Form

In the above example, underlying segments with the feature values /+ + –/ surface as [+++] via the intermediate representation in which the leftmost vowel spreads to the vowel to its right, which then spreads to the rightmost vowel. This intermediate level of representation encodes the hypothesis that it is the leftmost vowel that triggers harmony, as opposed to the medial vowel, which would be undifferentiated in a simple /++–/ ⇒ [+++] representation. Each segment has its projection or licenser. The leftmost vowel is licensed by its underlying form, and each vowel rightwards is licensed by its left neighbor via spreading.

Using representations of this level of detail make it possible to be extremely precise about which vowels initiate and undergo spreading. It is therefore possible to tailor the constraints on these representations to ensure that only typologically plausible representations are optimal. For example, the unattested 'majority rules' spreading pattern occurs when the source for vowel harmony ([+F] vs. [–F]) is determined by the number of vowels of each feature value in the input; the feature value with the greatest number vowels of that feature value is the source of spreading. In 'majority rules' spreading, the optimal output is determined by the feature value that requires the fewest changes from input to output. If a three-syllable item had two [+F] values and one [–F] value, the harmonic output will be [+F] regardless of the direction of spreading because changing from [–F] to [+F] only changes one vowel. Turbid Spreading achieves the desired result of avoiding 'majority rules' because direction is specified in the representation. Spreading may be left-to-right, right-to-left or bi-directional for a specific feature value (e.g., [+F]). Further, in order to satisfy the spreading constraint, all undergoing vowel segments must be projected by a neighboring vowel (which will incur a violation of faithfulness), regardless of whether the actual feature value has changed from the input to the output. Because the spreading constraint evaluates candidates at the intermediate level, the nature of the underlying form will not determine which vowels undergo changes to the representation: all vowels undergo changes to the representation in order to undergo spreading.

Spreading at the intermediate level also prevents the unattested 'sour-grapes' spreading, which pathologically occurs when a vowel that does not undergo spreading (a blocker) prevents spreading to all other vowels. For example, for the input /+ – –B/ (where /–B/ represents a vowel that cannot become [+F]), spreading from the first vowel (which would have otherwise occurred) to the second vowel is blocked. This occurs because the fully-faithful form ([+ – –]) and the intended optimal output ([+ + –]) both have a disharmonic sequence of [+F –F]. The fully-faithful form has only one change from the input to the output, and therefore fewer faithfulness violations. However, in Turbid Spreading, the representation of the fully-faithful form does not undergo spreading, and does not satisfy the SPREAD constraint. Because spreading, even if it does not continue to the edge of the word, is more important than faithfulness (in harmony languages), 'sour-grapes' harmony spreading (a pathological harmony pattern in which spreading the presence a non-participating vowel prevents spreading to vowels that would otherwise undergo harmony) can never occur under a Turbid Spreading analysis. Further, pathological interactions between deletion and vowel harmony (e.g., the unattested deletion of a vowel that does not undergo spreading) is avoided in Turbid Spreading because vowels can only be deleted on the surface level, and are still subject to harmony constraints. Deleting a non-participating vowel does not remove the disharmonic segment. Altogether, Turbid Spreading is a theory of vowel harmony that predicts a set of languages that is compatible with the languages that learners are equipped to learn.

While traditional methods in theoretical linguistics can be used to understand the distribution of linguistic patterns across the world, these traditional methods are limited in their ability to distinguish theories regarding the relationship between linguistic typology and learning biases. The substantively biased theory of learning (Wilson, 2006) states that typological restrictions in the world's languages are shaped by learning biases. A better understanding of the nature of cross-linguistic typology must come from understanding how languages are learned. While studying how natural languages are learned 'in the wild' (either in young children or in adult second language learners) can be a fruitful method for uncovering learning biases, there are many factors that are out of the researcher's control. For example, it is not possible to study whether and how unattested patterns are learned, as unattested patterns can never, by definition, appear in nature. Further, understanding inferences that learners make about ambiguous or noisy data is difficult to control for, as the researcher must make due with the input that the language learner receives, which (ethically) must be out of the researcher's control. Experimental methods, particularly the artificial grammar learning paradigm, can bypass these problems because the input to the learner is explicitly controlled for. For example, it is possible to train learners on unnatural or unattested patterns in order to better understand how learning biases may affect cross-linguistic typologies.

While the theoretical and experimental portions of the dissertation are presented separately, they are compatible in that the experimental work presents confirms the need to seriously consider the typological ramifications of a theoretical proposal. Chapter 7 confirms the need to avoid 'majority rules' in theoretical analyses of vowel harmony. Chapter 9 confirms the use of feature-based representations for phonological processes, as well as using abstract representations that can apply to a wide range of affixes and affix classes. Chapter 12 confirms the need for directional representations for harmony.

The experimental work presented in this dissertation also provides some insight into the nature of constraints for vowel harmony. For example, Chapter 10 distinguishes between restrictions on vowel harmony that arise from featural markedness constraints and restrictions that arise from representational constraints governing which vowels may spread harmony. In round harmony, high vowels are less likely to be the source of harmony than mid vowels, but mid vowels are less likely to undergo harmony than high vowels. This difference is due to differences in representation, as well as differences in featural markedness. Many languages do not permit mid round vowels in the language inventory, but do allow high round vowels in the language inventory. In addition, mid vowels are less likely to undergo harmony than high vowels. Because English allows mid round vowels ([o]), we expect learners to allow mid vowels to undergo harmony, which is confirmed by the results of Experiment 7. Because the perception of mid round vowels is enhanced via spreading, the marked representation of mid round vowels is supported by a separate constraint requiring spreading for mid round vowels (Kaun, 2004). However, no such constraint is required for high round vowels, because these vowels are perceptually salient. Because there is a constraint requiring mid round vowels to spread but no constraint regarding high round vowels, this theory of representations predicts that it should be easier to learn a language where only mid vowels spread harmony than a language in which only high vowels spread the round feature. This prediction is borne out in Experiment 8, in which participants were able to learn a round harmony language with mid vowel triggers, but not with high vowel triggers.

The experimental results in Chapter 12 provide further insight into the nature of harmony constraints, as well as their initial state in the adult learner. Learners exposed to an affix dominant harmony language (Experiment 12) were able to learn a harmony pattern where suffixes trigger harmony onto a stem, but were unable to learn a harmony pattern where prefixes trigger harmony onto the stem. When participants were trained on suffixes spreading to stems, they learned a general affix triggering harmony pattern and extend the affix-driven harmony pattern to prefixes. This asymmetry can be accounted for in Turbid Spreading because the trigger for harmony is part of the harmony representation (it is the segment that is licensed by its underlying form and is projected by its neighboring vowel). A constraint requiring that the segment which initiates spreading be an affix induces affix-triggering harmony. However, a conflicting constraint against prefixes initiating spreading accounts for the lack of prefix-driven harmony. This produces a typology where all affixes (suffixes and stems) can spread to stems. There are many languages in which suffixes are the only affixes that may spread to stems, but no language where prefixes are the only affixes that may spread to stems. This implies that a learner exposed only to prefixes triggering harmony will have to reconcile the fact that the language learnaning data presented to them cannot be generated by any grammar. The only options are to (i) induce a harmony pattern in which both prefixes are harmony triggers in addition to suffix harmony triggers or (ii) fail to learn the harmony pattern. The results of the present experiment suggest that learners, when given data that conform to an unattested pattern will fail to learn the pattern rather than induce a typologically plausible pattern. When participants are exposed to suffixes spreading harmony, they must upgrade the ranking of the constraint forcing affixes to harmonize as sources/triggers (above a faithfulness constraint). If the initial state of the adult learner has the constraint against prefixes below the faithfulness constraint, when the harmony constraint inducing affix spreading is ranked above the faithfulness constraint, it will automatically be ranked above the constraint against prefixes spreading, implying a harmony system in which both prefixes and suffixes may trigger harmony.

A truly integrated theory of phonology makes use of data from a wide range of sources: typological, computational and experimental. By ensuring that the representations for vowel harmony fall in line with typological considerations, are computationally tractable, and motivated by experimental results and learning biases, the theory presented in this dissertation is an example of an integrated approach to studying the language faculty.

1.4 Overview of the Dissertation

Chapter 2 provides an overview of pathologies that are predicted by previous analyses of vowel harmony using Optimality Theory. First, I discuss 'majority rules' alternations (e.g., /+ – – / ⇒ [– – –]; /++–/ ⇒ [+++]), when the direction of spreading is determined by the number of vowels of a particular feature in the input. However, this pattern never occurs in natural language; spreading is always determined by directionality or some dominant feature value, including stress. 'Majority rules' is predicted by non-directional harmony constraints that prefer the fewest possible faithfulness violations as long as all feature values match. Second, I discuss sour-grapes spreading, which are pathological systems predicted by theories that assign the same harmony violation for no spreading and spreading to a blocker, but differing faithfulness violations. In sour grapes spreading, if there is a segment that cannot undergo harmony, the harmony trigger fails to spread to all intervening vowels. Third, I discuss pathologies with deletion and epenthesis interactions, which pathologically occur when a theory allows an epenthetic vowel to increase or decrease the overall degree of violation of a harmony-driving constraint for the lexical item. Finally, I provide an overview of previous solutions to these pathologies, and what can be learned from these solutions. I also discuss why a representational approach to vowel harmony is appropriate.

Chapters 3 and 4 outline the goals of a representational approach to the problem, and gives a brief overview of Turbidity Theory (Goldrick, 2001), and its implementation in vowel harmony. This is followed by a full description of the proposed novel approach to vowel harmony Turbid Spreading, which makes use of the covert representations found in Turbidity Theory in order to capture the myopia generalization on vowel harmony. In Turbidity Theory, there is a covert level of representation that relates the input to the output. With these covert levels of representation, it is possible to account for derivational transparency, as well as provide an explicit representation for spreading. By being explicit about how spreading occurs, it is possible to avoid pathological rankings. Chapter 4 provides both an overview of how Turbid Spreading accounts for transparency and opacity, as well as how it avoids over-predicting unattested patterns such as 'majority rules', 'sour grapes' and pathological interactions with deletion and epenthesis.

Chapter 5 outlines the computational methodologies used to ensure that Turbid Spreading is free of typological pathologies. While Chapter 4 provides evidence that the pathologies described in previous literature are not present in Turbid Spreading, there is still the possibility that Turbid Spreading predicts other pathological systems that have not been previously cited. This chapter argues for the use of computational methodologies to provide an account of the full typology of Turbid Spreading. Using a combination of the Contenders Algorithm (Riggle, 2004) and a program for computing factorial typologies (Jason Riggle, personal communication), I extracted the factorial typology of vowel harmony for up to four vowels in the input. The Contenders Algorithm works with finite-state Optimality Theory to find all potential winners (contenders) for any given input and set of constraints. This use of the Contenders Algorithm involved writing all constraints on GEN required by Turbid Spreading into finite-state machines. The Contenders Algorithm combined all machines and used a shortest-best-path model to find all potential winners for all possible inputs up to four vowels. The output of the Contenders Algorithm was then fed into a program for computing typologies based on Elementary Ranking Conditions (ERC's (Prince, 2002)) for a factorial typology of the language (Jason Riggle, personal communication). Without epenthesis, the theory predicts 16 languages, all attested. With epenthesis, OT produced 68 languages, all attested.

Chapter 6 presents an overview of the experimental work, including a rationale for the experimental design and control conditions. I also include an overview of previous research using the artificial grammar learning paradigm. I summarize evidence from previous works that substantive biases on phonological, phonetic and grammatical naturalness drive learning.

Chapters 7 and 8 tie the theoretical results to the experimental work together, presenting the results from experiments testing for a cognitive basis against unattested harmony patterns such as majority rules and sour-grapes spreading. In Chapter 7, I employ the Poverty of the Stimulus Method to test whether learners are biased for directionally based harmony or majority rules-based harmony processes. The results of these experiments provide evidence that participants infer a directional harmony rule when trained on harmony data that is ambiguous between left-to-right spreading (or right-to-left in a separate condition) and majority rules spreading. These results suggest that the absence of majority rules harmony systems in the world's languages is not an accident, and support the need for OT analyses to avoid such typological pathologies.

Chapter 8 presents an experiment in which participants are trained on a vowel harmony rule with a non-participating vowel (transparent or opaque depending on the condition). This non-participating vowel is always the second vowel of three vowels in left-to-right harmony. At test participants are asked to choose between sour-grapes and non-sour-grapes spreading with the non-participating vowel. The results of this experiment were unclear because participants were unable to learn either transparent or opaque patterns in the non-participating vowel. Planned revisions to the design of the experiment, as well as potential reasons for the current result, are discussed.

Chapter 9 presents evidence for feature-based generalization and the substantively biased theory of learning. In this set of experiments, participants were trained on vowel harmony processes with 4 vowels from a 6 vowel inventory. At test, participants are exposed to all 6 vowels, and tested on their generalization of the harmony pattern to two novel vowels. Generalization to these novel vowels is an indicator of feature-based representations in the harmony processes they learn. The results of these experiments provide strong support for feature-based learning, but they also sho that such generalization to novel segments does not always occur. For example, learners exposed to a back/round harmony pattern generalized to novel mid vowels but not novel high vowels. The differential generalizations that we find across our experiments are interpreted as the result of learning biases on the nature of feature-dependencies and acceptability of vowel harmony triggers. Further, the pattern of generalizations followed the typological tendencies for vowels to trigger harmony (low vowels are generally opaque to rounding harmony), and support the hypothesis that typological restrictions on vowel harmony arise from learning biases.

Chapter 10 presents the results of two experiments on the nature of triggers and targets in round vowel harmony. In these experiments we test whether restrictions on round harmony triggers and targets are present as learning biases in our participants. One experiment tests whether mid vowels are better triggers for round harmony than high vowels; the other experiment tests whether high vowels are better targets for round harmony than mid vowels. The results for these experiments suggested a learning bias for mid vowel harmony triggers, which is consistent with the observed typology, but no bias for harmony targets. The lack of bias for mid vowel harmony targets may arise out of the vowel inventory for English, which allows round mid vowels. If inventory restrictions not present in English are the typical culprits for the typological generalization, it makes sense that English learners should of a harmony language will not follow the generalization. Because many languages ban mid round vowels, mid round vowels are unlikely targets for harmony.

Chapter 11 presents an experiment that tests the restrictive nature of back vowels in height harmony. In height harmony, back vowels are notoriously poor undergoers; few languages allow back vowels to undergo height harmony. We trained learners on either height harmony with a front vowel suffix alternation, and tested for generalization to a back vowel alternation, or trained learners on a back vowel alternation and tested for generalization to a front vowel alternation. We found robust learning for front vowel alternations but no learning or generalization for back vowel harmony alternation. Strikingly, learners exposed to back harmony alternations generalized to front vowels even though they showed no effect of training on back vowel suffixes, suggesting a strong bias against back vowels undergoing height harmony alternations and a bias towards front vowels undergoing height harmony alternations.

Chapter 12 provides the results of two experiments testing for the default nature of directionality biases in vowel harmony. Vowel harmony languages can typically be described in either a morphological description (e.g., stem-outward) or with a directional notation (e.g., left-to-right). In our experiment, participants were exposed to a prefixing-only harmony language and tested for generalization to novel suffixes (and likewise for suffix training). If learners infer a non-directional harmony pattern by default, they will generalize to novel affixes, but if they infer a directional harmony rule by default, they will not generalize to novel affixes. These experiments test for the default nature of directionality for both stem-outward harmony and affix-triggering harmony, as well as for a learning bias involving the typological generalization of a right-to-left bias in vowel harmony (Hyman, 2002b). Learners in these experiments were able to generalize to novel affixes. For stem-outward harmony, learners were able to generalize to both prefixes and suffixes, indicating a non-directional default to harmony. For affix-triggering harmony, however, learners were only able to learn suffix-triggering harmony, and not prefix-triggering harmony, suggesting that the preponderance of right-to-left spreading in vowel harmony found cross-linguistically derived from a learning bias against prefix harmony triggers.

Chapter 13 ties together the experimental and theoretical work presented in this dissertation to form an integrated theory of vowel harmony. I discuss the implications of the results of this work, including the need for integration of multiple tools in understanding language: theoretical, experimental and computational. I also discuss the implications for using theory to inform experiments and vice versa. Finally, I discuss problems with and prospects for the present proposals and lay out a research plan in order to better understand the nature of linguistic typology.

Chapter 2: Pathological Vowel Harmony Predictions

2.1 Introduction

This chapter discusses several of the pathologies found in previous OT analyses of vowel harmony, introduced by Wilson (2003a). Wilson (2003a) proposes that the over-generation of typologies in previous analyses arises from a failure to capture a fundamental property of long-distance spreading, a property Wilson refers to as myopia. While spreading typically applies to several segments in a single lexical item, the spreading process is actually iterative, applying to several vowels in a series of individual steps. Spreading is myopic because the process cannot 'see' beyond the current application of spreading. Therefore, the decision of whether to spread or not at each stage of the spreading process cannot be influenced by anything outside the immediate spreading domain.

The idea that vowel harmony applies iteratively is not a new one. Vago (1973) shows that simultaneous non-iterative rule application for vowel harmony produces ungrammatical results in Hungarian back vowel harmony. For example, an input with a front vowel stem and two back vowel suffixes (e.g., /kønyv+unk+hoz/ 'to our book') should have two applications of spreading, producing [kønyvynkhøz]. However, if spreading applies simultaneously without iterativity, there will only be a single application of the spreading rule *[kønyvynkhoz], leaving the final vowel unchanged, and the form ungrammatical.

The difference between rule-based applications of harmony and OT is that in rule-based applications, each potential locus for harmony is evaluated serially, leading to an implementation of spreading that is local. In OT, all potential loci of application are evaluated in parallel. This leads to non-local evaluation, which makes it possible for Optimality-Theoretic analyses of vowel harmony to predict non-local interactions.

In order to understand how different theories of Optimality Theory violate the myopia generalization and therefore, make different pathological predictions about the vowel harmony typology, it is important to understand the various theories of vowel harmony in OT, three of which I will describe here: AGREE, ALIGN and Span Theory. I will also describe the workings of Targeted Constraints later in this chapter. In this chapter I will often refer to vowels in terms of their feature value (e.g., [+] vs. [–]). Such abstraction refers to whether a vowel has the [+] or [–] feature value for the harmonic feature (e.g., [+ATR]). This is done to make it clear when segments agree in the relevant harmonic feature value[2]. Also, except where noted otherwise, I will for simplicity assume representations including a separate vowel tier (Hayes & Wilson, to appear; NiChisosain & Padgett, 2001).

2.1.1 AGREE

The AGREE constraint requires adjacent vowels to share the same phonological feature value.

(2) AGREE[F] (Bakovic, 2000; Lombardi, 1999; Pulleyblank, 2002): Adjacent segments must have the same value of the feature [F].

This constraint is satisfied whenever all vowels share the same feature value, regardless of the source of agreement (e.g., left edge or right edge of a domain) or the specific feature value that the features agree in (i.e., [+F] vs. [–F]). This constraint has the

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[2] This type of notation is too simplified to handle cases of multiple feature agreement as in parasitic harmony, but will be sufficient for the present discussion, in which features agree on only one dimension.

advantage that it favors harmony without invoking much machinery. Representationally, it assumes only that output segments are fully specified. However, in order to create restrictions on harmony (e.g., stem control, directionality effects), other constraints are required. Further, as I will show later in this chapter, the fact that this constraint uses such simplistic representations has important consequences for the factorial typology.

2.1.2 ALIGN

ALIGN, defined in (3) below, is an approach to vowel harmony that induces harmony in ways that are strikingly different from AGREE. First, spreading is autosegmental: representations are assumed to include tiers for features and associations between feature values– autosegments– and vowel root nodes. Second, the direction of spreading is encoded in the constraint. Third, violations of ALIGN are assigned gradiently, based on the distance of the disagreeing segment from the edge of the word. For each autosegment [αF], ALIGN is violated once for each vowel that is not associated with [αF] and that lies between [αF]'s associated segments and the designated edge of the harmonic domain. This means that spreading up to one segment from the edge is better than spreading up to two segments from the edge, and so on.

(3) ALIGN ([αF], R, PRWD, R):
Align the rightmost edge of a featural autosegment[3] to the rightmost edge of the prosodic word.
For a given [αF] autosegment, assign one violation to each vowel not associated with that [αF] autosegment between the rightmost edge of the word to the rightmost edge of the autosegment.

Following Archangeli and Pulleyblank (2002), I assume that gapped representations like the one in (4) below are not produced by GEN. For any pair of adjacent vowels that disagree in feature values, there will always be at least one violation of ALIGN.

(4) Impossible structure: non adjacent vowels sharing the same autosegment (not produced by GEN)
* e a e
   | |
 [+ATR]

I assume that bidirectional harmony is derived via two ALIGN constraints (i.e., ALIGN-R, ALIGN-L). Note that the ALIGN constraint is output oriented— the constraint can be satisfied by spreading of a non-underlying feature. The implementation of ALIGN is given in the tableau in (5) below.

[3] I assume that the rightmost edge of an autosegment refers to the rightmost segment associated with that autosegment.

(5) Hypothetical Rightwards Vowel Harmony

/– – + + –/	ALIGN[F]-R	ID[F]
a. [– – + + –] | | | | | [–F]$_1$ [+F]$_2$ [–F]$_3$	$*_1*_1*_1*_2$	
b. [– – + + +] | | | | | [–F]$_1$ [+F]$_2$	$*_1*_1*_1$	*
c. [– – – – –] | | | | | [–F]$_1$		**
d. [+++++] | | | | | [+F]$_1$		***

In the above tableau violations of ALIGN are indicated by subscripting each '*' with the index of the feature value that is not aligned at the right edge. For example, there are four violations of ALIGN[F]-R for candidate (a.) [– – + + –]. There are three unassociated vowels from the right edge of the [–F]$_1$ autosegment to the right edge of the word, inducing the first three violations of ALIGN. The final violation of ALIGN is incurred by the final vowel unassociated with the [+F]$_2$ autosegment. Candidate (b.) has three violations of ALIGN because there are three unassociated vowels to the right of the [–F]$_1$ autosegment. Candidates (c.) and (d.) have no violations of ALIGN because all vowels are associated to the same autosegment.

As will be argued for in this chapter, the directional, autosegmental nature of ALIGN prevents several typological pathologies. However, the fact that constraints are violated based on their distance to the edge will have important consequences for harmony pathologies as well.

2.1.3 Span Theory

Span Theory[4] is a theory of featural representations in which all feature values are represented through headed spans. For example a series of [+ATR] vowels [++++] can be represented as a single span (e.g., (+++±), where the underlined vowel is the head of the span). Each span has one and only one head, and all segments in a span must share the same feature value (e.g., *(±–) is not a valid span). There are several possibilities for representing a string of segments. If each segment is the head of a span, then there must be a span for each segment (±)(±)(±)(±). If the string of vowels is represented in a single span, then one segment is the head (e.g., (±+++) or (+++±)), and the segments must all share the same feature value. The decision to have one span with one head or several spans with several heads is based on a conflict between markedness (*AdjSpan) and faithfulness (ID), which requires each underlying feature corresponds to the *head* of the span).

The constraint *AdjSpan bans adjacent spans, inducing harmony. Because all segments within a single span must share the same value of a given feature, if *AdjSpan is satisfied, then harmony must be achieved since there can only be a single span. For example, the disharmonic string [+–] must have two spans (±)(–). However, when a vowel does not surface as ahead of a faithful span, it will violate faithfulness. The harmonic segment (±+) will have one violation of ID. In the tableau in (6) below, each faithful vowel is its own head, but this violates *AdjSpan.

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[4] Span Theory is an approach to long distance spreading that is similar to Headed Feature Domains Theory (Smolensky, 2006), which makes slightly different restrictions on the representations of feature spans. However, because McCarthy's paper on Span Theory (McCarthy, 2004) makes specific mention of harmony pathologies, I will focus on this approach. Both approaches represent the source of spreading via a 'head' of a feature domain/span.

Directionality in Span Theory is formalized by constraints aligning the span the head to one edge of the span. For example, Span-Hd-R requires that the head of a span be on the right edge of the span, simulating right-to-left spreading. However, there is nothing inherent in the harmony-inducing constraint *AdjSpan that requires spreading to be in any particular direction. In this way, Span Theory is like AGREE.

(6) Span Theory (McCarthy, 2004)

/i ɪ ɪ/	SPAN-HD-R	*AdjSpan(ATR)	ID[ATR]
a. (i̲)(ɪ̲)(ɪ̲)		*!*	
b. ☞ (i̲ i i)			**
c. (ɪ ɪ ɪ̲)	*!		**

Span Theory also contains constraints that require vowels of a particular feature value to be the head of a span. For example, HighHdATR is violated by any high vowel that is not the head of an [ATR] span. These constraints can help regulate which segments are the sources of harmony.

As mentioned above, the harmonic span (+̲+) will incur a violation of faithfulness. This is true regardless of whether the underlying form is /++/ or /+–/, because of the way in which faithfulness is defined in Span Theory. Span Theory uses a stricter version of faithfulness than those used in ALIGN or AGREE implementations of vowel harmony. In this version of faithfulness, the only way for a segment to satisfy faithfulness is to emerge as the head of a span in the output. For example, an underlying /+ATR/ vowel may incur a violation of faithfulness even if it emerges as [+ATR] in the output, if it is not the head of a faithful span. A fully harmonic candidate will have only one span, and only the head vowel of the span will satisfy faithfulness; all other vowels will violate faithfulness.

The harmony inducing constraint *AdjSpan can only be satisfied by a surface form with a single span, regardless of whether all of the vowels share the same feature value. For example, the mapping from /+++/ to (±++) satisfies the harmony inducing constraint *AdjSpan because the output contains only one span, but is violated by (±)(±+) (which has two spans), even though both (±++) and (±)(±+) have the same surface features. Even though all three vowels surface with the same feature value of their underlying form, only one satisfies faithfulness (the head). This formalization of faithfulness will have important consequences for harmony typology. I will demonstrate that while Span Theory does well at avoiding particular known pathologies, it is not immune to all pathologies.

The next section goes into detail on the harmony pathologies identified in the literature, and will discuss potential solutions to these harmony pathologies.

2.2 Harmony Pathologies

While Wilson discusses several typological pathologies induced by previous OT analyses of vowel harmony, I will focus on majority rules, sour grapes, dominance reversal, and blocking effects of epenthesis/deletion.

Majority rules is a pathological pattern that occurs when the majority feature value in the input determines the feature value that spreads. For example, the input /+– –/ will give right-to-left spreading and all [–] values: [– – –], but the input /++–/ will produce left-to-right spreading and all [+] feature values. This type of pathology occurs when the harmony inducing constraint has no say in either the direction of spreading or the preferred feature value for spreading. If the harmony inducing constraint only requires agreement, then the harmonic item with the fewest faithfulness violations will emerge, producing an unattested majority rules grammar.

Sour grapes harmony patterns occur when a blocker prevents spreading to vowels intervening between the source and the blocker. For the input /+ – –B/ (where 'B' denotes that the final vowel does not undergo harmony), the output [+– –] will be optimal rather than the desired [+ + –]. This type of pathology is produced when the harmony-inducing constraint does not localize the violation of harmony. In both the sour grapes candidate [+ – –] and the spreading candidate [+ + –], there is only one locus of disagreement (where + meets –). However, because the sour grapes candidate incurs no faithfulness violations, it will emerge as optimal.

Most models of phonology predict that a blocker can be deleted in order to satisfy harmony. For example, the input /+ –B/ could surface as [+], deleting the final vowel in order to satisfy the harmony-inducing constraint. This type of pattern is unattested. Epenthesis can also pathologically interact with vowel harmony. This is especially problematic for ALIGN constraints that assign more violations to disharmony as these violations occur further from the edge of the word. For example, the input /+ –B CC/ should surface as [+ – C – C], but if harmony is measured by the distance to the edge, epenthesis actually creates more disharmony, since the disharmony in [+ – CC] is one vowel from the edge, but the disharmony in [+ – C – C] is now two vowels from the edge. This permits a type of interaction that is unattested, in which epenthesis that would otherwise occur is prevented when a harmony blocker occurs anywhere in the form.

Constraints that measure the distance between the locus of disharmony and the edge of the word do not predict sour-grapes spreading. However, they do induce pathological interactions with epenthesis that would not otherwise arise; in avoiding one pathology, it may be possible to unintentionally create another. The analyst must therefore be extremely careful in determining the typological consequences of all proposals made for a harmony-inducing constraint.

The remainder of this section will provide further details regarding the nature of the pathologies listed above: majority rules, sour grapes, and interaction with epenthesis and deletion. I will also demonstrate previous solutions these pathologies, and reflect on the insights that these proposals give us for all future theories of vowel harmony in Optimality Theory.

2.3 Majority Rules

The majority rules problem of assimilation was first noted by Lombardi, who used AGREE to account for consonant place assimilation, but the AGREE constraint also applies to agreement in vowel harmony (Lombardi, 1999). The problem of majority rules for vowel harmony stems from the idea that vowel harmony is a bidirectional system, induced by a simple Markedness >> Faithfulness interaction; harmony is induced by some markedness constraint, which outranks featural identity. This interaction says nothing about the relative markedness of different harmonic forms. For example, in a bidirectional round harmony system, where AGREE[ROUND] (markednes) >> ID[ROUND], the round [bini] and the unround [byny] are equally harmonic for the input /biny/ because both satisfy AGREE and both have only one identity violation. This is illustrated in (7) below:

(7) AGREE >> ID

/biny/	AGREE[ROUND]	ID[ROUND]
[biny]	*!	
☞[bini]		*
☞[byny]		*

While the disharmonic form [biny] will not surface, some other constraint must decide which surfaces. For example, if *[+ROUND] >> *[–ROUND], then [bini] will surface.

(8) AGREE >> ID

/biny/	AGREE[ROUND]	ID[ROUND]	*[+ROUND]	*[–ROUND]
[biny]	*!		*	*
☞ [bini]		*		**
[byny]		*	**!	

The constraint that determines which of the two fully harmonic candidates should surface is crucial for an attested pattern to emerge. In the above ranking, the [–ROUND] harmonic candidate will only surface if it has the same or fewer ID violations as the [+ROUND] harmonic candidate. This is illustrated in (9) below.

(9) AGREE >> ID

/binygy/	AGREE[ROUND]	ID[ROUND]	*[+ROUND]	*[–ROUND]
[binygy]	*!		**	*
[binigi]		**!		***
☞ [bynygy]		*	***	

In this hypothetical language, the candidate with the fewest ID violations is predicted to be optimal. In other words, the number of vowels of each feature value determines what feature value will spread. Whichever feature value has the greatest number of vowels in the input will be the dominant vowel in the output. This majority rules pattern is completely unattested in natural language; there are no languages where

/binygy/ with two round vowels surfaces as uniformly round but /binigy/ with one round vowel surfaces as uniformly unround.

One way to avoid majority rules spreading and still use the AGREE constraint is through local conjunction (Bakovic, 1999). In his proposal, Bakovic makes use of local conjunction to establish a dominant feature value. The local conjunction of *[–ATR] and ID[ATR] penalizes any underlyingly /+ATR/ vowel that becomes [–ATR], inducing [+ATR] dominance by making it preferred for a [–ATR] vowel to become [+ATR]. Bakovic's definition for local conjunction, given in (10) below, asserts a universal ranking of the conjunction over its conjuncts.

(10) Definition of Local Conjunction (Bakovic, 1999, 2000)
- (a) Let A and B be constraints in *Con*.
- (b) The conjunction A $\&_i$ B is violated if and only if both conjuncts A and B are violated within the same domain i.
- (c) A $\&_i$ B >> A, B: The local conjunction of two constraints universally outrank each of its conjuncts.

By this definition, the local conjunction (within the domain of the segment) *[–ROUND] $\&_{SEG}$ ID[ROUND] must outrank both *[–ROUND] and ID[ROUND]. Because the local conjunction serves as the dominance constraint (i.e., the 'deciding' constraint between two harmonic outputs), and is universally ranked above featural identity, then there is no majority rules prediction. This is illustrated in (11) below. There are two [–ROUND] vowels in the input, but just one [+ROUND] vowel in the output, but the optimal output is [+ROUND].

(11) Local Conjunction prevents Majority Rules

/binigy/	AGREE[ROUND]	*[–ROUND] &$_{SEG}$ ID[ROUND]	ID[ROUND]	*[–ROUND]
a. [binigy]	*!			**
b. [binigi]		*!	*	**
c. ☞ [bynygy]			**	

While the local conjunction of markedness and faithfulness is able to derive dominance, it is dependent on the universal ranking of local conjunctions over their conjuncts to avoid a majority rules ranking. While this universal ranking produces the desired effects, there is some evidence that the universal ranking of local conjunction and conjuncts may not hold. Kiparsky and Pajusalu's (2003) analysis of transparency in vowel harmony makes use of local conjunctions in which one or both of the conjuncts may outrank the local conjunction. If their analysis is on the right track, then it is unclear whether the universal ranking of conjunction over conjunct is the right claim to make. When positing a universal ranking, there is always a question of whether there is an independent need for this universal ranking besides preventing unattested languages, which is not clearly demonstrated for the majority rules cases.

Another issue that arises from using a conjunction of markedness and faithfulness is that these conjunctions often produce unattested languages (McCarthy, 2007; Moreton & Smolensky, 2002). While some researchers have proposed constraints on local conjunction (Bakovic, 1999; Lubowicz, 2005; Moreton & Smolensky, 2002), it is still an open question as to the proper way to make use of the power of local conjunction without making faulty predictions.

Regardless of whether the local conjunction approach to majority rules is on the right track, we will see that it will not be adequate to avoid other pathologies, such as sour grapes, discussed below.

2.4 Sour Grapes Spreading

In vowel harmony, inventory constraints often prevent a vowel from undergoing harmony. For example, in ATR vowel harmony systems, [+ATR], low vowels are marked (by a constraint *[+ATR]/[–HIGH], as I will assume). If such an inventory constraint is ranked above the harmony inducing constraint, that vowel cannot undergo harmony. In the tableau below, stem faithfulness is high-ranked (stems are marked with a √). The high-ranked feature- co-occurrence markedness constraint prevents spreading to the low vowel [a].

(12) *F/G >> AGREE >> ID

/√bin-a/	*[+ATR]/ [–HIGH]	ID[ATR]$_{STEM}$	AGREE[ATR]	ID [ATR]
a. ☞[bina]			*	
b. [binæ]	*!			*
c. [bɪna]		*!		*

When there is a vowel that can undergo harmony intervening between the non-undergoer ([a]) and the vowel responsible for spreading, that intervening vowel should be unable to undergo harmony. Because vowel harmony is myopic, there is no reason that the presence of a non-undergoer elsewhere in the harmony domain should block spreading to other vowels. However, because spreading does not remove the AGREE violation, but still incurs an ID violation, it is predicted to be better to not spread at all. In (13) below, the fully-faithful candidate surfaces because it has the same number of agreement violations as the candidate with spreading, but fewer violations of ID.

(13) *F/G >> AGREE >> ID : Sour Grapes

/√bin-ɪ-a/	*[+ATR]/[–HIGH]	ID[ATR]$_{STEM}$	AGREE[ATR]	ID[ATR]
a. ☹ [binɪa]			*	
b. [biniæ]	*!			**
c. [bɪnɪa]		*!		*
d. ✓ [binia]			*	*!

Candidate (a.) has a ☹ symbol (indicating a pathological winner) next to it becaue the language that produces this candidate is unattested. There are no languages in which spreading only occurs if there are no harmony blockers. Note that without the low vowel, there is spreading to the high [–ATR] vowel.

(14) *F/G >> AGREE >> ID

/√bin-ɪ/	*[+ATR]/[–HIGH]	ID[ATR]$_{STEM}$	AGREE[ATR]	ID[ATR]
a. ☞ [bini]				*
b. [binɪ]			*!	
c. [bɪnɪ]		*!		*

Because Optimality Theory must optimize the entire structure in parallel, it is able evaluate whether spreading will decrease the number of agreement violations for the entire lexical item. But vowel harmony systems simply do not work that way. Spreading occurs regardless of whether there is blocker (non-undergoer) or not, regardless of the end state. The constraint that governs harmony must somehow prefer structures with spreading up to a blocker over incomplete spreading. The AGREE constraint in its basic form clearly does not do this.

Another prediction made by the bi-directional spreading constraint AGREE is that the presence of a non-undergoer can reverse the direction of spreading. This can ocur when stem identity is ranked below the agreement constraint, illustrated in (15) below.

(15) *F/G >> AGREE >> ID

/√bin-a/	*[+ATR]/[–HIGH]	AGREE[ATR]	ID[ATR]$_{STEM}$	ID[ATR]
a. [bina]		*!		
b. [binæ]	*!			*
c. ☞ [bɪna]			*	*

In this case, high-ranked AGREE forces harmony in the presence of a blocker, but harmony normally spreads from the stem outward, illustrated (16) below:

(16) *F/G >> AGREE >> ID

/√bin-ɪ/	*[+ATR]/[–HIGH]	AGREE[ATR]	ID[ATR]$_{STEM}$	ID[ATR]
a. ☞ [bini]				*
b. [binɪ]		*!		
c. [bɪnɪ]			*!	*

The presence of a blocker reverses the direction of spreading. This is referred to as 'Dominance Reversal' (Bakovic, 2000). Bakovic (2000) admits no knowledge of cases like the one above, in which a phonologically induced blocker reverses the direction of harmony. While Bakovic cites Turkana as a language in which some suffixes reverse the dominant value of the harmonic lexical item, this case is purely morphological. Finley (submitted) has argued that morpheme-specific behavior in harmony is generally very different from regular phonological harmony. In sum, there is reason to believe that the dominance reversal prediction made by AGREE is not a desired one.

Bakovic (2000) proposes a cyclic solution to sour-grapes within AGREE. In this solution, harmony applies cyclically for each morphological domain. With stem-controlled harmony, harmony applies to the stem, followed by each affix from the stem outward. This approach will work if the non-participating vowel happens to be in its own morpheme specified in a different cycle. However, this is not always the case, as stems may contain disharmonic segments. When a disharmonic vowel occurs in the stem there is no way to use the morphological boundary to enforce spreading to vowels within the stem. For example, suppose the input to a stem in an ATR harmony language contained the vowels /i ɪ a/ where /a/ is opaque to harmony. In this case, there is no way to use morphological cycles to induce spreading to the medial vowel. Further, not all harmony applies cyclically, stem outward, such as affix-controlled harmony. It is unclear how Bakovic's approach will handle disharmonic vowels in these cases. Finally, Bakovic's solution does not get at the underlying reason that AGREE makes the unattested sour-grapes prediction.

A novel finding in the present work is that one of the major reasons that for the failure of AGREE to account for myopia effects is that the theory that gives rise to the AGREE constraint prefers vacuous agreement to non-vacuous agreement. Vacuous agreement refers to agreement that does not change the underlying form of a vowel. For example, the input /– +/ ⇒ [++] involves non-vacuous agreement, but the input /++/ ⇒ [++] is vacuous agreement because there is no change in feature value. Both of the output forms satisfy AGREE, but non-vacuous agreement also incurs a violation of faithfulness. If two candidates have the same number of violations for AGREE, then it will be the number of faithfulness violations that determine which candidate is most harmonic. Since vacuous spreading has fewer faithfulness violations, all else being equal (i.e., comparing two fully harmonic candidates), vacuous spreading will always surface under an AGREE analysis. This preference can lead to sour-grapes harmony because agreement up to a disharmonic segment incurs just as many violations of the harmony-inducing markedness constraint as not changing any vowel features at all, but agreement will induce faithfulness violations.

Span Theory's (McCarthy, 2004) implementation of faithfulness addresses this issue. As discussed above, faithfulness in Span Theory is evaluated in terms of whether an underlying segment surfaces as a head of a span without changing its feature specification. For example, if [+ATR] /i/ surfaces as the head of a [–ATR] span, faithfulness is violated. Additionally, faithfulness is also violated if a [+ATR] /i/ surfaces as a non-head, even if it does not change its underlying feature value. There are three ways for a segment to violate faithfulness: surfacing as an unfaithful head of a span, surfacing faithfully but not as a head of a span, or surfacing unfaithfully as a non-head. For Span Theory, vacuous spreading incurs equivalent faithfulness violations as non-vacuous spreading. This removes the advantage for a failure to spread. For example, the input /i ɪ a/ where /a/ does not undergo harmony, the sour-grapes candidate (i)(ɪ a) incurs the same number faithfulness violations as the spread-right candidate (ii) (a) and are equally harmonic. The sour-grapes candidate no longer has an advantage over the spreading candidate, but some other constraint must force the sour-grapes candidate to fail in the optimization. This cannot simply be a constraint on head-alignment because both heads are aligned at the left edge in both candidates. The constraint that will always prefer candidate (d.) over candidate (a.) is a left-to-right directionally-evaluated version of the *AdjSpan constraint (Eisner, 2000) that prefers violations of *AdjSpan that are closest to the right edge of the word. In Chapter 4, this method is used to prevent further pathological predictions.

(17) *F/G >> *AdjSpan >> ID : Sour Grapes

/√bin-ɪ-a/	*[+ATR]/[–HIGH]	ID[ATR]$_{\text{STEM}}$	*AdjSpan	ID[ATR]
a. ☞ (b<u>i</u>)(nɪ<u>a</u>)			*	*
b. (b<u>i</u>niæ)	*!			**
c. (bɪnɪ<u>a</u>)		*!		**
d. ☞ (b<u>i</u>ni) (a.)			*	*

McCarthy demonstrates that Span Theory does not predict sour-grapes harmony in terms of nasal harmony. McCarthy follows Walker's (2000) universal hierarchy of values for nasality to account for the hierarchy of undergoers in nasal harmony. In Walker's account of nasal harmony, there is a universal constraint hierarchy for nasality *NASFRIC >> *NASGLIDE >> *NASVOWEL, etc. The place of ID[NASAL] in that hierarchy determines whether a segment will undergo nasal spreading. If, for example, a grammar has the ranking of *NASFRIC >> ID >> *NASGLIDE, then there will be no nasal fricatives, and fricatives will not undergo harmony but glides and vowels will. McCarthy adapts this hierarchy in Span Theory by creating a hierarchy of the domain head-forcing constraints like FRICHDORAL and forming a universal hierarchy. When *AdjSpan (*A-SPAN) is placed in between these constraints, the dividing line for harmony is created. This is illustrated in (18) below.

(18) Sour Grapes and Span Theory (McCarthy, 2004)

/mawasa/	FRICHDOR	*A-SPAN(nasal)	GLIDEHDORAL	VOWELHDORAL
a. (<u>m</u>)(<u>a</u>wasa)	*!	*	*	***
b. ☞ (<u>m</u>awa)(<u>s</u>a)		*	*	***
c. (<u>m</u>a)(<u>w</u>asa)	*!	*		***
d. (<u>m</u>awasa)	*!		*	***
e. (<u>m</u>a)(<u>w</u>a)(<u>s</u>a)		**!		***
f. (<u>m</u>)(awa<u>s</u>a)		*	*	***

The high-ranked FRICHDORAL constraint induces spreading from the left edge all the way to the fricative, despite the fact that candidates (a.- c.) all only incur one violation of

*A-SPAN. Candidate (d.) is fully harmonic but the fricative is not a head of its own span, incurring a violation of FRICHDOR. Notice that candidate (f.) is tied with the desired winner. This candidate has been added, and must be ruled out by an additional constraint, namely a constraint on head alignment.

(19) Sour Grapes and Span Theory (McCarthy, 2004)

/mawasa/	FRICHDOR	*A-SPAN(nasal)	GLIDEHDORAL	VOWELHDORAL	SPHDLEFT [–NASAL]
a. (m)(awasa)	*!	*	*	***	
b. ☞ (mawa)(sa)		*	*	***	
c. (ma)(wasa)	*!	*		***	
d. (mawasa)	*!		*	***	
e. (ma)(wa)(sa)		**!		***	
f. (m)(awasa)		*	*	***	*!

The vacuous spreading candidate (f.) loses because of the head-alignment constraint SPHDLEFT and, is harmonically bounded by (b.). While this example appears to be free of pathologies, there are other interactions with head-alignment that can create pathologies. The sour-grapes candidate can surface if the direction of spreading is allowed to reverse (e.g., if a language with left-to-right spreading allows for right-to-left spreading in the case of a disharmonic vowel). Because the harmony-inducing constraint *AdjSpan is inherently bi-directional, it is possible for spreading to occur in one direction on some occasions and the other direction on other occasions. While alignment constraints enforce a default direction, they may not be able to enforce directionality of spreading if these constraints are low ranked (Hansson, 2001). As Wilson points out, if a directional constraint is ranked below the harmony-inducing constraint *AdjSpan, then harmony will be bidirectional except in the case in which there is disharmony. For example, the ranking of SPANHD-R[+NASAL] >> SPANHD-L[–NASAL] should produce right-to-left harmony, but Wilson (2006) shows that the ranking of *A-Span(nasal) >> SPANHD-L[+NASAL] >> SPANHD-R[–NASAL] predicts bidirectional harmony if there is no blocker. This reversal of directionality is demonstrated in (20) below.

(20) Sour Grapes and Span Theory (Wilson, 2006)

/natwa/	*A-SPAN(nasal)	[–CONT] HDORAL	SPANHDR [+NAS]	SPANHDL [–NAS]
a. (n)(atwa)	*!	*		
b. (n)(atwa)	*!			*
c. ☞ (natwa)		*	*	
d. (na)(twa)	*!		*	

While SPANHDR[+NASAL] is violated by the winning candidate (c.), high-ranked *A-SPAN forces spreading from left to right. However, if the constraint against oral stops undergoing harmony is high-ranked, the directionality constraint will decide the optimal candidate, and require only right-to-left spreading.

(21) Sour Grapes and Span Theory (Wilson, 2006)[5]

/nata/	[–CONT] HDORAL	*A-SPAN(nasal)	SPANHDR [+NAS]	SPANHDL [–NAS]
a. (n)(ata)	*!	*		
b. ☹ (n)(ata)		*		*
c. (nata)	*!			
d. √ (na)(ta)		*	*!	

Candidates (a.) and (c.) are not optimal because the [t] is not a head of an oral domain. While the attested candidate is (d.), if constraints on how the heads are aligned were to be ranked in a particular way, (b.) will surface. In this example the heads of nasal spans must be on the right edge. This is bad news for candidate (d.) because spreading to the

[5] Note that the potential candidate (na)(ta) where [a] is nasal cannot be produced by GEN, because the head of a nasal span must be underlyingly nasal.

first [a] incurs a violation of the alignment constraint. The alignment constraint SPANHDR[+NAS] normally forces right to left spreading, but because this constraint is ranked below *A-SPAN(nasal), bi-directional spreading occurs if spreading can occur 'all the way'.

The problem with Span Theory in accounting for myopia is that the constraint that induces directionality is not directly implemented in the harmony-inducing constraint. Bi-directional harmony is the default if there are no harmony blockers. If the directionality constraints are low-ranked, directionality effects will emerge in the presence of harmony blockers.

The gradiently-evaluated ALIGN family of constraints avoids sour-grapes spreading. Because ALIGN is violated gradiently, spreading up to the blocking segment is better than spreading no spreading at all. However, because ALIGN can be satisfied by agreement, dominance reversal is predicted over spreading to the blocker.

(22) Hypothetical Rightwards Vowel Harmony

/+ – –B/	*+B	ALIGN[F]-R
a. [– – –B] | | | [–F]		
b. [+ + +B] | | | [–F]	*!	
c. [+ – –B] | | | [+F] [–F]		**!
d. [++ –B] | | | [+F] [–F]		*

While the gradiently-evaluated version of ALIGN leads candidate (d.) to harmonically bound the sour-grapes candidate, it does not rule out spreading in the reverse direction in the presence of a blocker. ALIGN only provides a partial solution to the sour grapes problem. Further, ALIGN suffers from pathological interactions with epenthesis and deletion, as discussed in the next section.

2.5 Epenthesis Blocking with ALIGN constraints

In this section, I argue that ALIGN produces pathological predictions in the case of epenthetic segments. ALIGN forces the harmonic feature value of the source vowel to spread to the left or right edge of a word. A violation of ALIGN-R is assigned to each vowel that does not share the autosegment of the vowel feature to its left, starting from the left edge of the domain, and likewise for ALIGN-L starting from the right edge of the domain. If there is both a non-undergoer and an epenthesis site after this blocker, epenthesis can fail because epenthesis increases the distance between the harmony source and the edge of the word. This is illustrated in (23).

(23) *F/G >> ALIGN >> ID

/bin-aCC/	*[+ATR]/[–HIGH]	ALIGN[ATR] -R	ID[ATR]$_{STEM}$	*CC#	ID[ATR]
a. ☞ [binaCC]		*		*	
b. [binæCC]	*!			*	*
c. [binaCəC]		**!	*		*

The problem is that in the languages of the world, epenthesis is not conditioned by whether a non-undergoer appears in the lexical item. A related problem is that vowels might become deleted in order to decrease the distance between the edge of the word and the harmony source, illustrated in (24).

(24) *F/G >> ALIGN >> ID

/bina-ɪɪ/	*[+ATR]/[–HIGH]	ALIGN[ATR]-R	ID[ATR]$_{STEM}$	MAX	ID[ATR]
a. [binaɪɪ]		*!**			
b. [binæii]	*!				*
c. [bina]		*!	*	**	*
d.☞[binii]				*	**

The non-undergoer itself is deleted, which is not a viable repair to non-undergoing harmony. If participating in harmony creates a disallowed segment, deleting that segment is cross-linguistically unattested. This problem arises because the harmony constraint, in looking at the global structure of the lexical item, forces unattested interactions with other constraints.

This section has argued that the typical OT constraints for vowel harmony make incorrect typological predictions. In the next section, I will explore targeted constraints as a possibility for avoiding harmony pathologies (Wilson, 2003a).

2.6 Targeted Constraints and Harmony Typology

This section addresses the targeted constraints theory, an alternative solution to typological pathologies, particularly those found in spreading. Targeted constraints were originally developed to account for the fact that in consonant deletion, it is always the first consonant to delete (Wilson, 2000, 2001). This approach uses perceptual similarity in order to identify or target repairs. For example, the constraint *CC is targeted such that the first C is perceptually closest to Ø. This makes it more harmonic to delete the first consonant over the second consonant. The approach has also been extended to account for cases of phonological opacity (Bakovic & Wilson, 2000; Chen-Main, 2007; Yarmolinskaya, 2005).

More recently, targeted constraints have been revised to account for unbounded spreading and myopia effects (Wilson, 2003a). This revision has two important differences compared to standard Optimality Theory, one to GEN and one to the nature of targeted constraints.

In this revised version of targeted constraint Optimality Theory, GEN is no longer infinite. Rather, GEN is produced by the constraints themselves. The idea is that each constraint specifies a locus of violation (for a spread constraint, this would be the first and the second vowel of /+ – –/), and GEN produces all possible repairs of that violation. From the input /+ – –/, the spread constraint would generate candidates set {[++–], [+– –], [– – –]}, which includes the faithful candidate plus all possible repairs to the violation of the constraint.

Because GEN produces candidates based on the specific violation for each specific constraint, GEN must apply multiple times. In the present version of targeted constraint OT, GEN applies in the order of the constraint hierarchy. For example, the highest-ranked constraint produces candidates that are evaluated by the constraint hierarchy. The next highest-ranked constraint produces candidates based on the optimal candidate from the previous application of GEN. This continues until all constraints have applied GEN. Targeted Constraints OT must apply serially, for as many times as there are constraints. However, if a constraint is not violated then only the faithful candidate is produced by GEN. For example, a harmony-inducing constraint will only produce [+++] from the input /+++/ because there is no violation to produce repairs for. This means that the majority of optimizations for OT will be vacuous because if only one candidate is produced by GEN, there is only one possible winner.

The other difference between standard OT and targeted constraint OT is that targeted constraints evaluate candidates based on a pre-specified preferred repair for a particular markedness constraint. This pre-specified repair is encoded within the constraint. In traditional Optimality Theory, the particular repair for a markedness constraint is determined by the ranking of relevant faithfulness constraints. For example, *CC can be repaired by deleting one of the consonants or by epenthesizing a vowel between the two consonants. A targeted constraint version of *CC will specify what the repair must be to satisfy the constraint (e.g., epenthesis or deletion of the first consonant). Targeted constraints are must be defined in terms of a locus of violation λ, and a repair δ. The locus of violation determines when a constraint is violated by the input, and is used to produce candidates for optimization. The repair specifies when a candidate truly satisfies the targeted constraint. For unbounded spreading, a sequence of two adjacent segments with different feature values is marked, (e.g., λ: *[+ –]), and the repair is specified (e.g., δ: [+ –] ⇒ [+ +]). For a given candidate, if the specified repair is performed, the harmony of that candidate increases. In other words proper repairs may cancel out markedness violations.

However, if an undesired repair is performed, (e.g., [+, –] ⇒ [–, –], [+], [Ø], etc.) the harmony of that candidate decreases; that candidate incurs an extra violation of the spreading constraint. The targeted constraints version of SPREAD is defined in (25) below.

(25) T-SPREAD[R] ([+F], PrWd) (adapted for vowel harmony from Wilson (2003a))
λ: A [–F] vowel that immediately follows (on the vowel tier) a [+F] vowel segment in the same PrWd
δ: [–F] → [+F]

As mentioned above, each constraint undergoes its own optimization in the order specified by the constraint hierarchy. However, a single constraint may undergo several optimizations. In the case of unbounded spreading, the targeted constraint may apply several times because the specified repair for the spreading constraint applies only to the original locus of violation in the input. For example, given the input /+ – – –/, the locus of violation for SPREAD[R] is the initial two segments. The locus of the repair only allows one segment to undergo spreading [+ + – –]. If T-SPREAD[R] ([+F], PrWd) applied just once, only one vowel would undergo harmony. However, if constraints are only allowed to apply as many times as needed to increase harmony, then spreading can proceed to the entire PrWd. The derivation for /+ – –/ is given below. Because targeted constraints are able to assign penalties and rewards for incorrect vs. correct repairs, differential notation is used to distinguish violations and removal of violations. If a reward for correct application of a repair removes a violation, it is written in parentheses (*). If a violation is added for an incorrect repair, that violation will be underlined <u>*</u>. Positive rewards are given with numerals (e.g., (1)).

(26) *T-SPREAD-R[+ATR, PrWd]

/+ – –/	*T-SPREAD-R[+ATR, PrWd]	ID[ATR]
a. + – –	*!	
b. – – –	<u>*</u>!	
c. ☞ + + –	(*)	*

Candidate (a.) does not repair the original violation of the spread constraint, and therefore incurs a violation of T-Spread. Candidate (b.) shows spreading in the wrong direction, which is a repair unspecified by the targeted constraint, and so it incurs a violation for improper repair. Candidate (c.) induces a novel locus of disagreeing vowels and is not fully harmonic, but the violation of the spread constraint is removed because this candidate correctly repaired the initial locus of violation. The initial locus of violation for SPREAD between was the between the first and second vowel, was properly repaired by changing the second vowel to match the features of the initial vowel. This repair receives a 'bonus' for inducing the proper repair, canceling out the new locus of violation between the medial and final vowels. Notice that there is no candidate [+++], which would otherwise be the winning candidate, because there are no violations of the targeted constraint. In Wilson's (2003) proposal, GEN only produces candidates that can repair the original violation of the constraint. It is impossible for GEN to produce the candidate [+++] with a change to the final vowel, because this change does not repair any constraint. In other words, GEN cannot anticipate future violations of SPREAD. Because the locus of violation is between the first and second segments, GEN can only produce repairs those segments. The potential [+++] violates this principle by producing a candidate with a repair to both the second and the final segment. It is this change to the final segment that cannot be produced by GEN.

The winner to the initial run of the targeted constraint is fed into another optimization, illustrated in (27) below.

(27)

/+ + –/	*T-SPREAD-R[+ATR, PrWd]	ID[ATR]
a. + + –	*!	
b. ☞ + + +	(1)	*

Candidate (a.) incurs a violation of the spreading constraint, but candidate (b.) is rewarded for making the proper repair, and since it has no violations of the spreading constraint, has a total positive violation. The winner of this output is fed into a third round of optimizations for this constraint. Each constraint undergoes a round of optimization in order of the hierarchy of the constraints, with the highest-ranked constraint first.

(28)

/+ + +/	*T-SPREAD-R[+ATR, PrWd]	ID[ATR]
a. ☞ + + +		

Because there is no locus for violation of the spread constraint, there is only one possible output, the fully faithful candidate. Since the input matches the output, the iterations of the spreading constraint stop.

This account has important, positive consequences for theories of vowel harmony. Majority rules effects are not predicted to be possible for two reasons. First, the direction of spreading is specified in the constraint. Therefore the dominant feature and the direction of spreading can be directly encoded. If these factors are directly encoded in the constraint and repair, majority cannot play a role in deciding the dominant feature value or direction of spreading. Second, since constraints are evaluated iteratively, there is no way to know what feature value is the majority. It is impossible for an input such as /+ – –/ to become [+++] in one step because such a candidate cannot be produced by GEN.

The iterative nature of the constraint evaluation has the greatest impact on myopia effects that occur in the presence of a blocker. For example, sour grapes spreading does not occur because spreading applies in single steps; it cannot see the non-undergoer further in the derivation. This is illustrated in (29) below.

(29) *T-SPREAD-R[+ATR, PrWd]

/i ɪ a/	*[+ATR, –HIGH]	*T-SPREAD-R[+ATR, PrWd]	ID[ATR]
a. i ɪ a		*!	
b. ☞ i i a		(*)	*

Candidate (a.) has no repair, and incurs a violation of the spreading constraint. Candidate (b.) incurs a violation of the constraint, but a reward for proper repair. The next iteration is given in (30) below.

(30) *T-SPREAD-R[+ATR, PrWd]

/i i a/	*[+ATR, –HIGH]	*T-SPREAD-R[+ATR, PrWd]	ID[ATR]
a. ☞ i i a		*	
b. i i æ	*!		*

Candidate (b.) violates the featural markedness constraint that prevents /a/ from participating in harmony. Candidate (a.) violates the spreading constraint, but incurs the fewest violations. This demonstrates that sour grapes spreading is not predicted to occur.

One problem with the present version of targeted constraints is that it no longer accounts for transparent vowels without additional theoretical assumptions and machinery. The original version of Targeted Constraints accounted for transparent vowels (Bakovic, 2000; Bakovic & Wilson, 2000) by making comparisons between candidates that are minimally distinct from each other- the transparent candidate to the fully-harmonic candidate. Because the current version of targeted constraints does not compare minimally distinct versions of candidates, and spreading occurs iteratively, there is no way to use targeted constraints to directly compare the transparent candidate to the fully-harmonic candidate.

The iterative version of targeted constraints could account for transparent vowels if it were possible to allow spreading to occur all the way through the transparent vowel, creating the fully-harmonic form, and then going back and changing the transparent vowel from an undergoer to a non-undergoer. Wilson's solution to transparency involves just this, using what he refers to as non-persistent constraints. The role of non-persistent constraints in the constraint hierarchy is temporary, and everything else about these constraints works precisely as the current version of targeted constraints; they generate candidates and evaluate them iteratively until the input matches the output. The difference is that for a non-persistent constraint, once the constraint finishes applying, that non-persistent constraint is removed from the hierarchy and cannot influence the output at a later stage in the derivation.

Transparency is allowed to occur when a non-persistent spreading constraint is ranked higher than the feature co-occurrence constraint that creates the non-participating, transparent vowels. The non-persistent spreading constraint applies first, allowing spreading to apply throughout the entire lexical item, creating a vowel prohibited by the feature co-occurrence constraint. The spreading constraint is then removed from the hierarchy, and the feature co-occurrence constraint applies, changing the vowel with the marked feature value to a vowel with unmarked feature value. Basically, the transparent vowel undergoes spreading in one step of the derivation, but this spreading is removed in a later step, returning the transparent vowel to its underlying feature value. Removing spreading from the transparent vowel creates disharmony, but because the harmony constraint is no longer in the hierarchy, the unmarked feature value will surface. Non-persistent constraints are similar to a rule-based account in which the harmony rule applies first to all segments in the lexical item creating an intermediate representation in which the entire lexical item is harmonic. This is followed by an inventory constraint or clean-up rule that creates the transparent segment by 'undoing' the spreading that applied to that segment.

One concern that arises with the introduction of non-persistent constraints is the power that such constraints can bring to the grammar. Is it possible to have a single constraint apply many times throughout the derivation? The addition of non-persistent rules adds more machinery to an already complex formal system. Further, this additional machinery adds an additional level of serialism to the OT grammar, pushing targeted constraints even further towards a rule-based system, raising the question of why Optimality Theory should be used at all, when rule-based systems are formally much simpler.

There is another issue with targeted constraints, having to do with the efficiency of the derivations. It is possible for a form to undergo spreading multiple times in a derivation. Such redundancy can occur when there are multiple potential loci of spreading. When there are multiple, conflicting loci for violations it is possible that a single vowel will undergo spreading multiple times. For example, the input /ɛ i ɛ / (with rightwards spreading) has two loci for spreading, the first two vowels and the final two vowels. It is possible that the final vowel (/ɛ /) will undergo spreading twice if the derivation proceeds as follows: (i) the medial vowel spreads to the final vowel (/i ɛ / ⇒ [ie]) , (ii) the initial vowel spreads to the medial vowel (/ɛ i/ ⇒ [ɛ ɪ]), and (iii) the medial vowel spreads again to the final vowel (/ɪ e / ⇒ [ɪ ɛ]). While the final output of this derivation satisfies the myopia generalization, it must pass through a stage where myopia is violated, and it must undergo spreading twice, creating an inefficient and redundant derivation.

This type of redundancy occurs in a language with the ranking *T-SPREAD-R[ATR, PrWd] >> ID[ATR] >> *[+HIGH, –ATR]. This ranking will induce rightward spreading from of the feature [ATR] for the input /ɛ i/ as illustrated in (31) below.

(31) *T-SPREAD-R[+ATR, PrWd]

/ɛ i/	*T-SPREAD-R[ATR, PrWd]	ID[ATR]	*[+HIGH, –ATR]
a. ɛ i	**!		
b. ☞ ɛ ɪ	1	*	*!
c. e i	$\underline{*}$	*	

However, if there is a third vowel, as in /ɛ i ɛ/, spreading is preferred for the second locus of spreading, illustrated in (32) below.

(32) *T-SPREAD-R[+ATR, PrWd]

/ɛ i ɛ/	*T-SPREAD-R[ATR, PrWd]	ID[ATR]	*[+HIGH, –ATR]
a. ɛ i e	(*)!	*	
b. e i e	($\underline{*}$)!	**	
d. ɛ ɪ e	1 (*)	**	*

All three candidates have the same violation profile for the spreading constraint. Candidate (a.) has a violation in the output from [ɛ i] but a reward for the proper repair of /i ɛ/. Candidate (b.) also has a reward for the proper repair of /i ɛ/, but a penalty for an improper repair of /ɛ i/. Candidate (c.) has a reward for the proper repair of /ɛ i/, but a penalty for an improper repair of /i ɛ/. Candidate (a.) surfaces because it has the fewest ID violations without violating the markedness constraint *[+HIGH, –ATR].

In the second iteration of spreading, the initial vowel spreads to the medial vowel because this is the only option that will satisfy the spreading constraint. Not spreading at all incurs a violation, spreading leftwards receives a penalty for improper repair, but spreading rightwards to the medial vowel receives a reward.

(33) *T-SPREAD-R[+ATR, PrWd] Round 2

/ ɛ i e /	*T-SPREAD-R[ATR, PrWd]	ID[ATR]	*[+HIGH, –ATR]
a. ɛ i e	*!		
b. e i e	*!	*	
c. ☞ ɛ ɪ e	(*)	*	*

In the final round of spreading, the final vowel returns to its original [–ATR] specification, as spreading to the final vowel is the only option that will satisfy the spreading constraint

(34) *T-SPREAD-R[+ATR, PrWd] Round 3

/ ɛ ɪ e /	*T-SPREAD-R[ATR, PrWd]	ID[ATR]	*[+HIGH, –ATR]
a. ɛ ɪ e	*!		
b. e i e	*!*	**	
c. ☞ ɛ ɪ ɛ	1	*	*

Interestingly, if one more vowel is added to the input to create /ɛ i ɛ i/, the derivation proceeds in only one step. The input /ɛ i ɛ i/ has three loci for spreading. The first /ɛ i/ is repaired properly in candidates (a.) and (c.), giving them a reward. Candidates (b.) and (d.) do not repair this locus of spreadong, keeping the same violation of SPREAD. The second locus of spreading / i ɛ/ is properly repaired in candidates (b.), (c.) and (d.) but improperly repaired in candidate (a.). The third locus of spreading /ɛ i/ is properly repaired in candidates (a.) and (c.), unrepaired in candidate (b.) and improperly repaired in candidate (d.). While candidate (c.) repairs all loci for spreading properly, it creates two new loci for spreading creating two novel violations of SPREAD.

(35) *T-SPREAD-R[+ATR, PrWd]

/ɛ i ɛ i/	*T-SPREAD-R[ATR, PrWd]	ID[ATR]	*[+HIGH, –ATR]
a. ☞ ɛ ɪ ɛ ɪ	(<u>*</u>) 1	**	**
b. ɛ i e ɪ	(<u>*</u>)(*) *!	**	*
c. ɛ ɪ e ɪ	(*)(*)1	***!	**
d. ɛ i e i	(<u>*</u>)* !	*	

The input In the tableu in (35) above, candidate (a.) surfaces in one step because all other candidates either create novel loci for repair do not properly repair more candidates than candidate (a.). Candiate (c.) has the same total number of violations for SPREAD, but more violations of ID, allowing candidate (a.) to surface.

When there are large numbers of loci for spreading, as in this example, calculation of violations becomes increasingly complicated and may be up to subtle variations in how violations might be assigned. This may turn out to be a problem for the learner in inferring how to deal with large inputs or multiple spreading cites, and may create grammars in which spreading follows one derivation with one set of loci for spreading, and another set of derivations with another set of loci for spreading.

While targeted constraints will make the appropriate prediction in situations with multiple loci for violations, the solution is rather inelegant. In the first example above, /ɛ i ɛ/ the final [–ATR] vowel [ɛ] became [+ATR] in one iteration, and back to [–ATR] in another iteration of spreading. The most plausible solution to myopia will find the best loci for spreading immediately, rather than after several iterations of spreading. Finally, the fact that the first iteration of spreading /ɛ i ɛ / ⇒ [ɛ i e] is a violation of myopia implies that this theory of spreading does not naturally account for locality effects. While later stages of the derivation 'clean-up' this violation, there is an assertion here that myopia violations are possible at intermediate stages of the derivation. It is unclear why myopia violations are only possible at intermediate stage but not at the final stage, if it is a fundamental property of spreading that it be myopic. This also raises the question of whether any stage of derivation that violates myopia could ever be a final stage. If it could, then targeted constraint OT will predict some violations of myopia. The ideal solution to myopia should be able to provide myopic solutions at all levels of the derivation.

Targeted constraints offer a valuable insight into the iterative nature of spreading, but this formulation of targeted constraints cannot straightforwardly deal with transparency. Further, the solutions to situations when there are multiple loci of spreading are inelegant and redundant, requiring spreading to the same vowel multiple times, and pose different types of derivations for different sets of loci of spreading.

2.7 Prospects for Accounting for the Myopia Generalization

This dissertation presents a representational approach for avoiding pathological predictions in vowel harmony. The most obvious strating point is to consider what produces realistic typologies and what produces problematic typologies.

Non-directionality of harmony constraints creates unwanted interactions. When the inherent harmony constraint does not specify the direction of spreading, pathological interactions are predicted. For example, if the direction of spreading is determined by the feature values of the input, then majority rules occurs. If direction of spreading is inherent in the harmony-inducing constraint, there is no way to derive majority rules. Additionally, I described the pathological prediction made by Span Theory, in which direction can reverse in the presence of a non-undergoer (Wilson, 2006). Therefore, it seems that in order to avoid pathologies, the direction of spreading must be directly encoded in the harmony inducing constraint.

One potential problem with directly encoding directionality in the harmony-inducing constraint is the fact that experimental results (Chapter 9) suggest that learners infer a non-directional harmony rule when exposed to ambiguous harmony data. For example, learners exposed to harmony applying from stems to suffixes in a suffixing only learning data set will generalize the harmony pattern to novel prefixes, suggesting that the learners inferred a stem-outward (non-directional) harmony system rather than a left-to-right harmony system. There is an issue in encoding directionality in the harmony-inducing constraint, while setting up the system so that non-directionality is inferred by default. We will come back to this issue in Chapter 10.

The implementation of featural identity can also have a major impact on whether pathological interactions can be avoided. In sour-grapes pathologies, the candidate without spreading incurs the same violation of the harmony-inducing constraint but fewer faithfulness violations as the typologically sound competitor. However, in Span Theory, only span heads satisfy faithfulness. Representations for spreading are present in vowels that do not overtly change their underlying feature value. In order to avoid typological pathologies, spreading must be implemented as assimilation to the feature value of the source of spreading, regardless of whether the assimilated segment changes its feature value.

Finally, the locus of spreading must be represented locally rather than globally. In Targeted Constraints, spreading is represented in the form of derivations; each iteration of spreading is achieved as a single optimization of the grammar, applying multiple times. Each optimization can only implement spreading to a single vowel, deriving the locality requirement for spreading. This has important consequences for avoiding the typologies found in ALIGN constraints. In ALIGN constraints, each locus of spreading is defined by the entire domain for spreading (e.g., prosodic word), rather than in terms of the individual vowel that undergoes spreading. Because of this, other interactions such as epenthesis that occur outside the local domain of spreading may have an effect on spreading. A theory of harmony that avoids typological pathologies must make each iteration of spreading local. One positive feature of targeted constraints is that the representations are local in the sense that each iteration of spreading is represented by one pass through the grammar.

Targeted constraints do seem to be successful at avoiding typological pathologies, but at the cost of inefficient derivations, and the need for complicated machinery which require several levels of violation (standard violations, penalties for improper repair, and rewards for proper repair). In this dissertation, I propose that the insights of targeted constraints can be replicated in a more intuitive way, through enriched representations. The next chapter will discuss representational options for characterizing vowel harmony, specifically using Turbidity Theory (Goldrick, 2001).

Chapter 3: Turbidity Theory

3.1 Introduction

The proposal made in this dissertation is that a unified solution to harmony pathologies is possible by enriching the set of representations for vowel harmony. Assuming an Optimality Theoretical approach, one must adopt a theory of representations that are compatible with Optimality Theory. Turbidity Theory (Goldrick, 2001) is a theory of hidden (turbid) structure in phonological representations that will serve as a starting point for a theory of representations for vowel harmony. Turbidity Theory uses covert representations in order to capture opaque phonological processes, but I will demonstrate in Chapter 4 that these covert representations can also be used to capture the iterative, directional nature of vowel harmony.

Beyond the representational advantage for a theory of vowel harmony, Turbidity Theory is a good choice for a theory of representations for vowel harmony because it brings several advantages for work in Optimality Theory, particularly, providing a solution to the fact that standard OT is inable to handle opaque interactions. Turbidity Theory, as a theory of abstract representations is able to accommodate opaque interactions such as compensatory lengthening (Goldrick, 1999, 2001), interactions (Revithiadou, to appear), derived-environment Effects (van Oostendorp, 2006a). In addition, Turbidity Theory also provides an account of the phonetics-phonology interface (van Oostendorp, 2006b). By adopting Turbidity Theory as an approach to representations in vowel harmony, all the benefits of Turbidity Theory come along automatically. These solutions to previous problems provide the independent evidence needed for an added level of representation in phonological structure; hidden structure is needed for more than just vowel harmony.

This chapter is divided into two sections. The first section discusses the general nature of Turbidity Theory, and the second section discusses a previous application of Turbidity Theory to vowel harmony, and why Turbidity Theory alone is not enough to avoid myopia violations.

3.2 Turbidity Theory

There are several reasons why a representational approach to harmony is an attractive option. First, research on representations within Optimality Theory has been relatively scarce, and any advancement for a theory of representations for OT will be helpful to better understand the nature of phonological knowledge. It is possible that the pathological predictions made by many OT analyses come not from the OT machinery itself, but from the representations that were borrowed into the machinery. Adopting representations drawn from SPE (Chomsky & Halle, 1968) and autosegmental approaches to vowel harmony (Clements, 1976) makes sense as a starting point, but there is no reason to believe that the appropriate representations for OT are the same as the standard representations for other frameworks. More research is needed to determine what types of representations are most suitable for Optimality Theory. Taking a representational approach to vowel harmony will only further this end, and can only bring more to our understanding which facets of the human language faculty Optimality Theory is able to account for. Our knowledge of how vowel harmony is implemented in the grammar is extremely limited. Taking a representational approach to the myopia problem will only contribute to our ability to make predictions about the cross-linguistic typology of vowel harmony, and the larger typology of phonological processes beyond harmony. While the present theory of representations for Optimality Theory takes a novel approach to abstract levels of representation, they are in no way 'more abstract' or invoke more structure than previous theories of phonological representations. Because the representations in Turbidity Theory are constrained, the types of interactions that can occur are limited. Further, understanding the nature of the representation that will serve as an optimal candidate can help the analyst formulate constraints that will guarantee the optimal representation to surface, avoiding pathological representations.

The basic premise of Turbidity Theory (Goldrick, 2001) is that for every segment, there is a relationship between the abstract representation, the projection (represented by the up arrow$\uparrow$) and the surface representation, the pronunciation (represented by a down arrow $\downarrow$). This projection/pronunciation distinction is analogous to the phonology/phonetics distinction. The projection is an abstract phonological specification of the segment (phonology), while the pronunciation is the phonetic implementation, or surface realization of that element (phonetics). In the unmarked case, a segment's pronunciation is identical to its projection, however it is possible for a projection and a pronunciation to carry different feature values. When projection and pronunciation are mismatched, the RECIPROCITY constraint is violated.

Goldrick's test case for Turbidity Theory is compensatory lengthening in vowel deletion. In Luganda, the case analyzed by Goldrick, compensatory lengthening occurs when two underlyingly adjacent vowels in the input surface as one long vowel[6]. This is represented with two vowels, each projecting a separate mora. The first vowel (V_1) is

---

[6] Though other cases of compensatory lengthening occur when a consonant deletes, and the adjacent vowel lengthens to compensate.

deleted, but its timing unit is preserved through a pronunciation relation to V_2. V_1 projects a mora, but that mora is pronounced by V_2. Because only one vowel is pronounced on the surface, the constraint against pronouncing adjacent vowels (*VV⇲) is satisfied. This is illustrated in (36) below. A solid line represents mutual projection and pronunciation.

(36) Vowel Lengthening via Deletion

$$\begin{array}{ccc} \mu_1 & & \mu_2 \\ \uparrow & \searrow & | \\ V_1 & & V_2 \end{array}$$

μ_1 is projected by V_1, but is pronounced by V_2. While (36) depicts the optimal representation for compensatory vowel lengthening, constraints are needed to rule out alternative representations. As mentioned above *VV⇲ prevents pronunciation of two adjacent vowels. RECIPROCITY penalizes mismatches in projection and pronunciation, and is violated in (36) because the first mora is projected by V_1 but pronounced by V_2. Other constraints required for this analysis include: V-WT↗, all vowels must project their own mora, PRONOUNCERT⇲ (violated in (36)), all root notes must be pronounced and PRONOUNCEμ⇲, all moras must be pronounced. In addition, the faitfulness constraint MAX only penalizes complete deletion of the vowel, mora and all, projection and pronunciation. The full ranking and tableau are given below, with (36) repeated as the winning candidate (e.).

(37) Vowel Lengthening in Turbidity Theory (Goldrick 2000)

/V_1 V_2/	*VV↘	MAX	V-WT↗	PRONOUNCEμ↘	RECIPROCITY	PRONOUNCERT↘
a. [V_2] μ_2 | V_2		*!				
b. [V_2] μ_2 | V_1 V_2			*!			*
c. [V_2] μ_1 μ_2 ↑ | V_1 V_2				*!		
d. [V_1V_2] μ_1 μ_2 | | V_1 V_2	*!					
e.☞[V_2:] μ_1 μ_2 ↑↘ | V_1 V_2					*	*

Candidates (a.)-(c.) pronounce a short V_2 but are fatal for different reasons. Candidate (a.) has full deletion of V_1 and so violates MAX. Candidate (b.) fails because V_1 does not project a mora. Candidate (c.) fails because the mora associated with V_1 and is projected but not pronounced. Candidate (d.) is completely faithful without violating reciprocity, but fails because it violates *VV↘. Candidate (e.) is the optimal candidate because both moras have a projection, and both vowels are pronounced. Candidate (e.) violates reciprocity because the pronunciation of μ_1 is V_2. There is also a violation of PRONOUNCERT because the first vowel is deleted.

Turbidity Theory posits multiple forms of representation in phonological representation, the pronunciation and the projection. Turbidity Theory formalizes abstract levels of representation into Optimality Theory. Such formalism shows much promise for providing an account of some of the most difficult things to account for in OT, such as opacity effects and complex representations in vowel harmony.

Recently, there has been increased interest in Turbidity Theory for solving problems in phonology and morphology that require multiple levels of representations, including opacity as well as morphological exponence. van Oostendorp (2006b) and Revithiadou (to appear) have proposed revised versions of Turbidity Theory, combining the containment theory of faithfulness (Prince & Smolensky, 1993/2004, 2006) with turbid representations. The basic idea is that projection relations can be thought as a way of representing the underlying form of a structure in the output. In van Oostedorp's "colored containment" theory, the input structure is maintained (contained) in the output. In colored containment, this idea is maintained with a constraint on GEN that forces projection lines to be both inalterable and to reflect the underlying form of the segment. The analyses that make use of Turbidity Theory exemplify the promise that a turbid theory of representations for vowel harmony has for solving problems in phonology. The revisions that have been proposed suggest, however, that Turbidity Theory in its original form may not be adequate to solve all problems of opacity in phonology. In the next section, I show how the present version of Turbidity Theory does not avoid harmony pathologies.

3.3 Turbidity Theory and Vowel Harmony: Goldrick (1999); Uffmann (2006)

The projection and pronunciation representations used in Turbidity Theory are also applicable to vowel harmony. In his account of vowel harmony, Goldrick (1999) assumes that all vowels that undergo spreading are projected by the feature value of the source vowel. Transparency occurs when a vowel undergoes spreading (is projected by the feature value of the source) but pronounces its underlying feature value.

(38) Transparent vowel (Goldrick 1999)

[–ATR] [+ATR]

[ɛ ɪ ɛ]

In (38) above, the leftmost vowel is the source of spreading, and spreads its [–ATR] value to the two vowels to its right. The medial vowel is transparent, and is therefore projected by the [–ATR] feature of the source vowel, but pronounces [+ATR].

Uffmann (2006) proposes a slightly revised version of Turbidity Theory in order to account for vowel harmony representations. This account of harmony differs from Goldrick's in that transparent vowels are skipped by the source vowel. Transparent vowels do not project their feature, and are therefore skipped by spreading, but opaque vowels project their underlying feature and block spreading. Since projection and pronunciation constraints are separate, it is possible to predict whether a language will have transparent or opaque vowels.

(39) Transparent vowel

[+ATR] [–ATR] [–ATR]

V V V

In (39), the [–ATR] vowel is not projected, which allows for the first [+ATR] vowel to spread past the [–ATR] vowel. Non-projection somehow allows pronunciation lines of different feature values to not be subject to the line-crossing principle.

(40) Opaque Vowel

```
[+ATR]   [–ATR]        [–ATR]
   |        |                ↑
   V        V                V
```

In (40), the projection of the [–ATR] vowel makes it impossible to spread past this vowel to the third vowel. Instead, the opaque vowel spreads its underlying feature. Because both Uffman's and Goldrick's proposals make use of the same harmony inducing constraint (ALIGN), and make the same predictions about vowel harmony typology, I will refer only to Goldrick's proposal from here on.

The use of turbid representations makes it possible to account for transparency: projection accounts for spreading, pronunciation accounts for surface disharmony. Spreading at the projection level involves autosegmental representations that are almost identical to those found in previous OT analyses of harmony that require ALIGN constraints. These representations are problematic because they do not capture the iterative nature of spreading: the source of spreading can spread its projected feature value any number of segments, at any distance. In order for this representation to be optimal, the spreading constraint has to be non-local. This is because the source of spreading and the undergoers of spreading are not necessarily adjacent, as in the example in (38)/(39) in which the final vowel projects the feature value of the initial vowel. In order to capture this non-local relationship, non-local constraints like ALIGN are required. As discussed in Chapter 2, this class of harmony-inducing constraints are subject to myopia violations and pathological interactions with epenthesis and deletion.

Non-local constraints like ALIGN are also problematic for the present representations because they do not encode the directional nature of spreading such that the leftmost autosegment is the source of spreading. For example, in (38) if the medial (transparent) vowel were the source of spreading, then there would be no violation of reciprocity, as in (41) below. This would also satisfy ALIGN and harmony because the autosegment would be anchored at both edges.

(41) Transparent vowel becomes source of spreading

```
 [e  i  e]
   \ | /
  [+ATR]
```

The use of projection and pronunciation with an ALIGN constraint are not enough to avoid harmony pathologies. While there is a start, more work needs to be done on the representations for spreading. First, the iterative nature of spreading must be encoded in order to capture avoid pathologies derived from non-local interaction. Second, the source of spreading must be encoded such that the source is preferred at the edge of the harmonic domain. For example, left-to-right spreading should enforce the source to be at the left edge of the harmony domain. In order to do this, directionality of spreading must also be encoded within the harmony-inducing constraint. Direction is only partially encoded in the autosegmental representations of ALIGN used in Goldrick's formulation, but there is no way for the ALIGN constraint to strictly enforce spreading in a particular direction because ALIGN is satisfied by agreement regardless of the position of the source vowel. Revisions to the implementation of harmony must directly encode direction in both the representation and the harmony-inducing constraints. Finally, because the representations in Goldrick's formulation rely on a single trigger to spread to multiple undergoers, the representation of transparent vowels is forced to violate the line-crossing principle. Revising the framework to encode local iterative representations will avoid line-crossing in the representations.

The question remains how to use Turbidity Theory to provide a local, iterative, directional representation of spreading that can be enforced without pathological constraints like ALIGN and AGREE. One way to create a locus for local, directional application of spreading is to separate projection and pronunciation on separate tiers (Uffmann, 2006). If each vowel has its own projection, then it is possible to have each vowel spread its projection to its neighboring vowel, as in (42) below. Spreading occurs when a vowel projects its feature to its immediate neighbor. This creates a representation of spreading that is both local and directional because the source of spreading for any given harmony undergoer is directly encoded in the representation (its neighboring vowel). Further, by separating projection from pronunciation, there are no line-crossing violations.

(42) Projection from the Projection Level form

/[+ATR] [+ATR]/	Underlying Form
↓	
[+ATR] ← [+ATR]	Projection/Phonological Level
[+ATR] [+ATR]	Surface/Phonetic Level

In Chapter 4, I describe the implementation of these revisions in greater detail, demonstrating how separating projection and pronunciation provides a way to implement directional, iterative and local spreading without violating the myopia generalization.

Chapter 4: Turbid Spreading

4.1 Introduction

In this chapter, I extend previous work on Turbidity Theory with a novel proposal for turbid representations in vowel harmony. The chapter is structured into four parts. First, I present the proposed theory of representations for Turbid Spreading, demonstrating how it differs from Goldrick's (1999, 2000) original proposal. I also present the requirements on GEN that constrain the representations. Second, I present the constraints that induce the optimal representations for vowel harmony, including directional SPREAD constraints, featural identity and constraints regulating various levels of representation. Third, I present a demonstration of how vowel harmony can be implemented using turbid representations. I provide examples of general spreading, and show how the proposal accounts for non-participating vowels. This demonstration includes an explanation for how Turbid Spreading avoids typological pathologies, specifically interactions of vowel harmony and epenthesis. Fourth, I provide a preliminary analysis of bi-directional dominant-recessive vowel harmony.

4.2 Alterations and Additions to Turbidity Theory: Turbid Spreading

In this section, I explore the additions and alterations made to standard Turbidity Theory that constitute the theory of Turbid Spreading proposed here. In Turbid Spreading, the feature value for each segment is represented in terms of a triple: underlying form: projection form: surface form. All segments have a projection value (with the exception of some epenthetic vowels). The projection is interpreted differently from Goldrick's formulation, in which each vowel feature has a pronunciation representation, and must also be licensed by a projection. In Turbid Spreading, all features have a projection for each feature value, which are each represented on a separate tier. This creates three levels of representation: the underlying form, the surface form, and an intermediate, projection/phonological level, exemplified in (43) below.

(43) Three Levels of Representation

/[+ATR/	Underlying Form
[+ATR]	Projection/Phonological Level
[+ATR]	Surface/Phonetic Level

The underlying form is the standard formalization of the underlying representation: the input to the phonological optimization; it is found in the lexicon. The surface/pronunciation form represents what is actually pronounced by the speaker, and is the representation subject to phonetic interpretation. The phonological/projection level is an intermediate representation that represents phonological processes, such as spreading.

The notion of multiple tiers of representation is not new. In Goldsmith's harmonic phonology (Brentari, 1998; Goldsmith, 1993; Wiltshire, 1992), there are multiple levels of representation where different phonological processes occur. The present proposal is analogous to this, as the projection level corresponds to the W (word) level and the pronunciation corresponds to the P (phonotactic) level (Goldsmith, 1993; Wiltshire, 1992). In this framework, phonological and phonetic rules apply at different levels of abstraction, thereby creating a typology of interaction of various processes involving various types of rule interaction depending on the level of representation at which different processes apply. The work presented here draws on the insight that interaction of processes involves various levels of abstraction in the representation, as will be addressed in the discussion of epenthesis and vowel harmony.

4.2.1 Restrictions on Projection

In Turbid Spreading, each feature value is licensed by a single projection. This projection is represented on the intermediate level of representation, the projection level, and the source of this projection is notated with an arrow pointing to the feature value on the projection level. The source of the projection may be the underlying form of that particular segment, representing a phonologically unchanged (faithful) representation (↓) (44), from a neighboring projection value (←, →) (45), representing phonological spreading, or from the pronunciation (↑) (46), representing a phonetically-induced change to the abstract representation.

(44) Projection from the Underlying form

/[+ATR/	Underlying Form
↓	
[+ATR]	Projection/Phonological Level
[+ATR]	Surface/Phonetic Level

(45) Projection from the Projection Level form

/[+ATR/	Underlying Form
[+ATR] ← [+ATR]	Projection/Phonological Level
[+ATR]	Surface/Phonetic Level

(46) Projection from the Surface/Phonetic Level

/[+ATR/	Underlying Form
[+ATR]	Projection/Phonological Level
↑	
[+ATR]	Surface/Phonetic Level

There are several restrictions on the projection. First, a feature at the phonological /projection level may only have one projection, and all segments with an underlying representation must have a projection (epenthetic segments need be projected, and I will return to this issue shortly).

(47) Banned Projection: Multiple Projections

* /[+ATR] [–ATR] [+ATR]/	Underlying Form
↓ ↓	
[+ATR] →[+ATR] ←[+ATR]	Projection/Phonological Level
[+ATR] [+ATR] [+ATR]	Pronunciation/Surface Level

In the structure in (47) above, the second vowel's [ATR] feature is projected by the first and last vowels. This type of representation is not allowed, and will never be produced by GEN. The second restriction is that the source of the projection has to match the feature value at the projection level.

(48) Banned Projection: Mismatched Features from Pronunciation

* /[+ATR/	Underlying Form
[+ATR]	Projection/Phonological Level
↑	
[–ATR]	Surface/Phonetic Level

(49) Banned Projection: Mismatched Features from Underlying Form

* /[–ATR/	Underlying Form
↓	
[+ATR]	Projection/Phonological Level
[+ATR]	Surface/Phonetic Level

(50) Banned Projection: Mismatched Features from Neighboring Vowel

* /[+ATR/ /–ATR/	Underlying Form
↓	
[+ATR] ← [–ATR]	Projection/Phonological Level
[–ATR] [–ATR]	Surface/Phonetic Level

In (48)-(50) above, the source of the projection is [–ATR] but the projected value is [+ATR]. This type of representation is banned, and will never be produced by GEN. In other words, both sides of the arrows in the pictorial representation must match.

One final restriction on spreading is that the source of spreading must be faithful to its underlying form (i.e., it must be projected by its underlying feature,). This restriction prevents representations of the type illustrated in (51) below where an underlyingly /–/ feature spreads a [+] autosegment (e.g., /– – –/ ⇒ [+ + +]).

(51) Banned Representation

* / [–ATR]		[–ATR]/	Underlying Form
[+ATR] ↑	→	[+ATR]	Projection/Phonological Level
[+ATR]		[+ATR]	Surface/Pronunciation Level

The structure in (51) is banned because the underlying feature value of the initial vowel is [+ATR], but it projects [–ATR] without spreading. The structure in (52) represents the only way for a vowel to induce spreading; the underlying feature of the initial vowel spreads at the projection level to the final vowel.

(52)

/[+ATR] ↓		[–ATR]/	Underlying Form
[+ATR]	→	[+ATR]	Projection/Phonological Level
[–ATR]		[+ATR]	Pronunciation/Surface Level

Example (52) illustrates the possibility for a vowel to change its feature value without spreading. This would occur if the vowel is projected by its pronunciation or pronounces a different feature value than its projection. The restriction on the source of spreading does not prevent 'abstract' analyses (Hyman, 2002a); if an underlying value changes, it still may spread its underlying feature value.

This concludes the discussion of constraints on GEN, which are summarized in (53) below.

(53) Restrictions on Gen

a. Feature values on both sides of projection arrow must match
b. All underlying feature values projected by one and only one element: underlying form, surface form, projection level
c. The initiator of spreading must be projected by its underlying feature value[7]
d. Deletion occurs at the pronunciation level only
e. Epenthesis occurs at the pronunciation level or the projection level

These constraints limit the number of candidates that can appear in a given optimization, and are essential for limiting the number of potential candidates and limiting an explosion of possible representations.

4.2.2 Representation of Deletion and Epenthesis

In Turbid Spreading, deletion occurs only at the pronunciation level, meaning that the underlying form and the projection level are always present in the representation.

(54) Deletion

/[+ATR/	Underlying Form
↓	
[+ATR]	Projection/Phonological Level
Ø	Surface/Phonetic Level

Deletion at the pronunciation level allows us to represent compensatory lengthening in the same manner as inGoldrick's (2001) proposal, in which deletion targets a surface form only and not the abstract representation of the segment.

Epenthetic vowels must have featrures present at the pronunciation level, but may optionally have representations at the projection level. Epenthetic vowels that are only representated at the pronunciation level are straightforward to represent, as illustrated in (55) below.

[7] The initiator of spreading need not be a vowel, and thus the first vowel to initiate spreading may not be projected by its underlying form (but from a consonant, for example). Because the present analyses are restricted to vowel interactions, all vowels must be projected by the underlying form to initiate vowel harmony.

(55) Epenthesis At the Pronunciation Level

Ø	Underlying Form
Ø	Projection/Phonological Level
[+ATR]	Surface/Phonetic Level

Epenthetic vowels with representations at the projection level are more complex to represent. The projection cannot come from the underlying form, as there is no underlying representation for epenthetic vowels. Therefore, the projection of an epenthetic vowel must come from a neighboring segment or the surface form, as illustrated in (56) below.

(56) Epenthesis At the Projection Level

Ø	Underlying Form
[+ATR]	Projection/Phonological Level
↑	
[+ATR]	Surface/Phonetic Level

All epenthetic vowels with projection representation may participate in harmony just as non-derived segments participate. However, vowels that are epenthesized at the pronunciation level are transparent to harmony. Because constraints on spreading require the initiator of spreading to be projected by the underlying form (or the projection level), epenthetic vowels may not initiate spreading when they are projected at the surface level. I will return to discuss the typology of epenthesis and vowel harmony in greater detail (in section 4.3.4) following a discussion of how vowel harmony is instantiated in Turbid Spreading.

4.2.3 Representation of Spreading

I assume that spreading is an abstract process and therefore occurs at the projection level. In rightwards spreading, the initial vowel spreads its projection (from the its underlying form) to the closest vowel to its right. This vowel may then spread its projection to the right, and onwards iteratively until spreading reaches the right edge of the word. This is illustrated in (57) below:

(57) Rightwards Vowel Harmony

/[+ATR] [–ATR] [–ATR]/	Underlying Form
↓	
[+ATR] → [+ATR] → [+ATR]	Projection/Phonological Level
[+ATR] [+ATR] [+ATR]	Pronunciation/Surface Level

In (57), left to right spreading occurs from the initial vowel, which is projected by its underlying [+ATR] feature value. This [+ATR] projection spreads to the second vowel. This means that while the second vowel was underlyingly [–ATR], it is now projected by [+ATR]. This [+ATR] projection continues to spread to the right, and the final vowel projects differently from its underlyingly [–ATR] value. In this example, all vowels pronounce the same value of their projected values, meaning that all vowels pronounce [+ATR].

Spreading need not change an underlying feature value; a projection may link to another projection regardless of whether it alters the underlying projection of the segment. For example, a [+ATR] segment may link to another [+ATR] projection, illustrated in (58) below.

(58) Rightwards Vacuous Spreading

/[+ATR]	[+ATR]	[+ATR]/	Underlying Form
↓			
[+ATR] →	[+ATR] →	[+ATR]	Projection/Phonological Level
[+ATR]	[+ATR]	[+ATR]	Phonological Level

There are two ways for a segment to fail to participate in harmony. The first is at the projection level: the segment fails to undergo spreading at the projection level. The second is at the pronunciation level; the vowel may undergo spreading at the projection level, but fail to pronounce the projected feature value. These two options yield either a an opaque vowel or a transparent vowel. In the first case, the vowel will be opaque because the projection fails to spread past the non-participating vowel. In the second case, the vowel is transparent because the projection can spread through the non-participating vowel. These are given in (59) and (60) below.

(59) Transparent Vowel Harmony

/[+ATR]	[–ATR]	[–ATR]/	Underlying Form
↓			
[+ATR] →	[+ATR] →	[+ATR]	Projection/Phonological Level
[+ATR]	[–ATR]	[–ATR]	Pronunciation/Surface Level

In (59), the projection spreads from left to right through the non-participating vowel. All three vowels project [+ATR], but the medial, non-participating vowel pronounces [–ATR], while the other vowels pronounce [+ATR].

(60) Opaque Vowels

/[+ATR]	[–ATR]	[+ATR]/	Underlying Form
↓	↓		
[+ATR]	[–ATR] →	[–ATR]	Projection/Phonological Level
[+ATR]	[–ATR]	[–ATR]	Pronunciation/Surface Level

In (60), the projection from the initial target vowel does not spread to the medial, non-undergoing vowel, but the projection of this non-undergoer is able to continue to spread rightwards, thereby behaving as an opaque vowel.

4.2.4 Constraints on Vowel Harmony

With this general representational structure in place, it is now necessary to formalize the constraints that will yield the optimal representations for vowel harmony. The constraints that work to produce harmony are: SPREAD, ID, RECIPROCITY and Featural Markedness. I will also discuss the constraints that govern epenthesis and deletion.

4.2.4.1 SPREAD

I assume that harmony constraints have directionality built into them. While Bakovic (2000) argues against this, the above demonstration that inherently bidirectional constraints like AGREE predict sour-grapes spreading and that theories that encode direction with a secondary constraint as in Span Theory and headed feature domains create unattested interaction, provide strong motivation to investigate spreading constraints that encode directionality.

The harmony-inducing constraint, defined in (61) below, assigns a violation for failing to spread. The most intuitive method for determining whether the spreading constraint has been satisfied is to look for a horizontal arrow in the specified direction for spreading. For example, to spread from left to right, the harmonic feature of the first vowel must be projected by its underlying feature value, and the harmonic feature of the second vowel must be projected by the harmonic feature of the first vowel. Spreading is defined in the representation as sending the projection of one feature to the features of its neighboring vowel. Spreading is represenated as a horizontal line so for each horizontal line, that is missing, a violation is given for SPREAD-dir[F].

(61) SPREAD-R[F]
For all non-initial vowels, for each feature value [αF] on the phonological level, assign one violation if there is not a rightward-pointing projection arroworiginating at that feature value belonging to a rightward adjacent vowel.

(62) SPREAD-L[F]
For all non-final vowels, for each feature value [αF] on the phonological level, assign one violation if there is not a leftward-pointing projection arroworiginating at that feature value belonging to a leftward adjacent vowel.

I assume that these harmony constraints are evaluated directionally (Eisner, 2000). What directional evaluation does is break up the evaluation of the constraint in terms of each segment in the input. For example, SPREAD-R is evaluated from the leftmost vowel first, followed by each additional vowel, rightwards. This provides a formal mechanism for denoting the exact locus of each violation of spreading. This allows the analyst to localize the violations of SPREAD-R, such that a violation of SPREAD at the right edge of the word is worse than a violation at the left edge. This is similar to the effect of constraint violation found in the ALIGN family of constraints, in which (for example) failure to spread rightwards is worse at the beginning of a word because the fewer vowels that intervene between the disharmonic segments and the end of the word, the better the harmonic feature is aligned to the end of the word. What directional evaluation does is localize each violation, and thereby avoiding the pathological long-distance interactions that ALIGN constraints predict. Directional evaluation computes violations differently for each vowel in the input, meaning that epenthesized material will not affect the severity of disharmony for each individual failure to spread. The example in (63) below illustrates the use of directional evaluation for the input /+ – – – –/ (I use simple [+] and [–] symbols to reflect [+F] and [–F] of the harmonic feature value).

In (63) below, each candidate incurs a single violation of SPREAD-R. Candidate (a.) fails to spread to the first vowel, candidate (b.) fails to spread to the second vowel, and candidate (c.) fails to spread to the final vowel. With directional evaluation, each locus of spreading is divided into a separate evaluation (or separate constraint), with the ranking of the first locus for spreading ranked highest. Failure to spread from left-to-right is worse at the leftmost locus of violation. This produces iterative, myopic behavior of vowel harmony because left-to-right spreading must start at the leftmost edge, even if spreading elsewhere in the word would be advantageous. For ease of reference, a subscript is placed next to each violation of SPREAD to indicate its location. This location also serves as a tag for severity of the violation. In future tableaux, only subscripts will be used.

(63) Directional Evaluation of SPREAD-R

/+ – – –/	SPREAD-R		
	V1-V2	V2-V3	V3-V4
(a.) / + – – – / ↓ ↓ + – → – → – [+ – – –]	$*_1!$		
(b.) / + – – – / ↓ ↓ ↓ + → + – → – [+ + – –]		$*_2!$	
(c.) ☞ / + – – – / ↓ ↓ + → + → + – [+ + + –]			$*_3$

It is important to note that the division of SPREAD into different constraints in the tableau does not mean that another constraint could intervene between the different loci for potential violations. For example, it is impossible to rank ID in between SPREAD-R-V1-V2 and SPREAD-R-V2-V2; the ranking SPREAD-R-V1-V2 >> ID >> SPREAD-R-V2-V3 is impossible because the spread constraint is evaluated independently of other constraints. The fact that it is evaluated differently for different positions in the input has no bearing on its ranking with respect to other constraints.

This method of formalizing the directional nature of the SPREAD constraint was proposed in the original formulation of Optimality Theory (Prince & Smolensky, 1993/2004). In this formulation of constraint violation, the location of a particular violation can bear a particular weight. A violation at the beginning of the word will have a more severe violation than the middle of the word, which is more severe than a violation at the end of the word. This type of violation assessment does not make any alterations in the method that EVAL performs its computations. Rather, this method simply marks the location of violation and assigns a severity based on this location. In Chapter 5, the SPREAD constraints are formalized in precisely this manner. For example, for a word with four vowels, a violation of SPREAD-R at the left edge of the word is worth –100, -10 for the second vowel, and -1 for the third vowel (the final vowel vacuously satisfies SPREAD-R because there is no vowel for it to spread to). These distinctions have the effect of distinguishing between different violations of SPREAD and assigning variable weight to these different violations.

4.2.4.2 RECIPROCITY

The reciprocity family of constraints enforces uniformity of feature values between the pronunciation level and the projection level. Segments whose projection features do not match their corresponding pronunciation features incur a violation of RECIPROCITY. This includes mismatches that occur because the pronunciation feature has been deleted, but the projection still remains. Deleted vowels will incur a violation of RECIPROCITY. However, if there is no feature value at the projection level, RECIPROCITY is vacuously satisfied. Epenthetic vowels must satisfy RECIPROCITY.

(64) RECIPROCITY
Assign one violation for every feature value [αF] which does not have a corresponding value [αF] at the phonetic level.

RECIPROCITY is evaluated as a comparison between the projection level and the pronunciation level, and is completely independent of the input. RECIPROCITY violations can occur when the underlying feature value changes (65) but also when there is no change to the underlying form (66).

(65) Violation of Reciprocity

[–ATR]	Underlying Form
↓	
[–ATR]	Projection/Phonological Level
[+ATR]	Surface/Phonetic Level

(66) Violation of Reciprocity

[–ATR]	Underlying Form
[+ATR] ← [+ATR]	Projection/Phonological Level
[–ATR]	Surface/Phonetic Level

However, if the underlying form changes its feature value, RECIPROCITY may be satisfied if the projection and pronunciation values match. In (67) below, the pronunciation and projection are both [+ATR] and satisfy reciprocity, even though the underlying form is [–ATR].

(67) Satisfaction of Reciprocity

[–ATR]	Underlying Form
[+ATR] ← [+ATR]	Projection/Phonological Level
[+ATR]	Surface/Phonetic Level

If the projection of a vowel comes from its surface form, there is no way for that vowel to violate reciprocity, as the feature value of the surface form dictates the feature value of the projection level.

(68) Projection from the Surface Form Necessarily Satisfies Reciprocity

[–ATR]	Underlying Form
[+ATR]	Projection/Phonological Level
↑	
[+ATR]	Surface/Phonetic Level

4.2.4.3 Featural Identity

While RECIPROCITY governs identity between the projection and the pronunciation levels, featural identity (ID[F]) governs the relationship between the underlying form and the projection level. The version of featural identity here is more strict than standard identity; it is not enough for the underlying form and the projection level to share the same feature value; the projection of the vowel must come from the underlying form, otherwise ID is violated.

(69) ID[F]
Assign one violation for every segment whose underlying form does not project the feature [F] onto that segment, whose projection comes from its pronunciation form or a neighboring segment.

ID[F] is violated by any segment that is projected by its surface representation or the projection of one of its neighbors.

(70) Violation of ID[ATR]

[±ATR]	Underlying Form
[–ATR] ← [–ATR]	Projection/Phonological Level
[–ATR]	Surface/Phonetic Level

(71) Violation of ID[ATR]

[±ATR]	Underlying Form
[+ATR] ↑	Projection/Phonological Level
[+ATR]	Surface/Phonetic Level

In (70) and (71) above, the feature value of the underlying form is identical to the feature value of the projection, but because the vowel is not projected by the underlying form, it will violate ID[ATR]. In (72) below, ID[ATR] is satisfied, even though the surface form is not identical to the underlying form (but this does violate RECIPROCITY, described above). Because the underlying form projects this vowel, there is no violation of ID[ATR].

(72) Satisfaction of ID[ATR]

[+ATR]	Underlying Form
↓	
[+ATR]	Projection/Phonological Level
[–ATR]	Surface/Phonetic Level

4.2.4.4 MAX and DEP

MAX and DEP are the standard constraints for accounting for deletion and epenthesis respectively. MAX, defined in (73) below is violated whenever a vowel present in the underlying form does not appear in the surface.

(73) MAX
Assign one violation for each feature at the phonological level that has no corresponding feature at the surface level.

(74) Deletion Violates MAX

/[+ATR]/	Underlying Form
↓	
[+ATR]	Projection/Phonological Level
Ø	Surface/Phonetic Level

Note that the representation in which the projection level is also deleted is not produced by GEN.

DEP, defined in (75) below is violated differentially depending on where epenthesis occurs. If epenthesis occurs at the projection level, there is a single violation of DEP, once for each empty level of representation (one on the input level). However, if epenthesis occurs at the pronunciation level, that candidate will incur two violations of

DEP, one for the empty representation on the projection level, and one for empty representation on the input level.

(75) DEP
For each feature at the phonetic level, assign one violation for each missing corresponding feature at the phonological or underlying levels.

(76) Surface Epenthesis: Two Violations of DEP

Ø	Underlying Form
Ø	Projection/Phonological Level
[+ATR]	Surface/Phonetic Level

While epenthesis at the projection level has only one violation of DEP, it will incur a violation of SPREAD, either SPREAD-R or SPREAD-L depending on where the feature value of the spreading comes from. In order to avoid a violation of SPREAD, a language may choose to epenthesize at the pronunciation level and incur two violations of DEP.

(77) Phonological Epenthesis: One Violation of DEP

Ø	Underlying Form
[+ATR]	Projection/Phonological Level
↑	
[+ATR]	Surface/Phonetic Level

4.2.4.5 Featural Markedness

The final type of constraint that interacts with vowel harmony is featural markedness. For simplicity, as a stand-in for all feature co-occurrence constraints, I will assume a single feature co-occurrence constraint in the following analysis of vowel harmony: *[+ATR, –HIGH]. Notice that I have only been concerned with the representation of a single feature value ([ATR]). I assume that all vowels have threeleveled representations for each feature, ATR, high, etc., but that for ease of exposition, this other feature representation will not be included unless necessary.

(78) *[+ATR, –HIGH]: Assign one violation to each vowel that is [+ATR] and [–HIGH] on the pronunciation level

This concludes our description of the constraints that I will use for vowel harmony interactions. The next section of this chapter puts everything together and illustrates not only how the present proposal accounts for basic facts of vowel harmony— transparency and opacity— but also how the proposal is able to avoid violations of myopia, a major goal of this work identified in Chapter 2.

4.2.5 Vowel Harmony

I assume that vowel harmony is induced by a markedness-faithfulness constraint interaction such that harmony applies when SPREAD[F] outranks ID[F]. When *[+ATR, –HIGH] outranks both SPREAD[ATR] and ID[ATR], non-high vowels will not participate in harmony. What decides whether the non-participating vowel is transparent or opaque is the ranking of RECIPROCITY with respect to SPREAD. If RECIPROCITY is ranked above SPREAD, the non-participating vowel is opaque. If RECIPROCITY is ranked below SPREAD, the non-participating vowel is transparent. For this initial demonstration, I ignore the effects of MAX and DEP, but will return to the this issue in section 4.3.4. I also assume a high-ranked faithfulness constraint to the feature [HIGH] (e.g., ID[HIGH]) such that no vowels will change their height feature to satisfy the SPREAD constraint.

The interactions between the constraints presented above are given in the tableaux below. Representations in the tableaux are arranged such that the top line in GEN indicates the underlying form, the second line indicates the projection level, and the third line represents the pronunciation level. The final line, where applicable, is an IPA representation of the output of the segment. In (79) (a.), underlying [+ATR] spreads from the initial vowel to the final vowel violating ID. Candidate (b.) also allows spreading, but pronounces [–ATR], incurring a fatal violation of RECIPROCITY. Candidate (c.) has no spreading, and therefore violates the spread constraint. Notice that projection from the pronunciation level (candidate (d.) is harmonically bounded by candidate (c.) because it violates faithfulness in addition to the SPREAD constraint.

(79) Vowel Harmony and Turbid Spreading (Opacity Ranking)

/i ɪ/	*[+ATR, –HIGH]	RECIPROCITY	SPREAD[ATR]R	ID[ATR]
(a.) ☞ / + – / ↓ + → + [+ +]				*
(b.) / + – / ↓ + → + [+ –]		*!		*
(c.) / + – / ↓ ↓ + – [+ –]			*!	
(d.) / + – / ↓ + – ↑ [+ –]			*!	*

The general scheme for vowel harmony involves SPREAD >> ID. When a non-participating vowel is present, the ranking of RECIPROCITY determines whether the non-participating vowel is transparent or opaque.

4.2.5.1 Opacity and Transparency

Opacity and transparency are determined from the relative ranking of reciprocity and the spreading constraint. This is illustrated in the next tableaux. In (80) the non-participating vowel /ɛ/ is flanked by [+ATR] to the left and a [–ATR] vowel to its right. The transparent candidate (b.) spreads [+ATR] all the way through the non-participating vowel.

(80) Transparency and Turbid Spreading

/i ɛ ɪ/	*[+ATR, –HIGH]	SPREAD[ATR]-R	RECIPROCITY	ID[ATR]
(a.) / + – – / ↓ + → + → + [+ + +]	*!			**
(b.) ☞ / + – – / ↓ + → + → + [+ – +]			*	**
(c.) / + – – / ↓ ↓ ↓ + – – [+ – –]		$*_1!*_2$		**
(d.) / + – – / ↓ + → + → + [+ – –]			**!	

The forms in candidates (a.), (b.) and (d.) successfully spread the [+ATR] feature to all vowels. Candidate (a.) fails because it produces the ungrammatical non-high [+ATR] vowel. Candidate (d.) fails because it produces two reciprocity violations. Candidate (c.) has no spreading, incurring two violations for lack of spreading.

Tableaux (81) illustrates that transparency still applies even when the underlying form is transparent, when the non-participating [–ATR] vowel is flanked by two [+ATR] vowels.

(81) Transparency and Turbid Spreading

/i ɛ i/	*[+ATR, –HIGH]	SPREAD [ATR]-R	RECIPROCITY	ID[ATR]
(a.) / + – + / ↓ ↓ + – → – [+ – –]		*!		*
(b.) ☞ / + – + / ↓ + → + → + [+ – +]			*	**
(c.) / + – + / ↓ ↓ ↓ + – + [+ – –]		$*_1*_2$!		
(d.) / + – + / ↓ ↓ + – → – [+ – –]		$*_1$!		*

Candidates (a.), (b.), and (c.) all involve spreading to a single vowel. The high-ranked featural markedness constraint prevent spreading to all vowels, meaning that the optimal candidate must violate SPREAD-R. Candidate (b.) wins because it is the only candidate in which the two final vowels undergo spreading, incurring the fewest SPREAD-R violations without violating featural markedness.

Tableaux (82) and (83) have the same inputs as (80) and (81) respectively, but have RECIPROCITY ranking higher than SPREAD. This creates opacity.

(82) Opacity and Turbid Spreading

/i ɛ ɪ/	*[+ATR, –HIGH]	RECIPROCITY	SPREAD[ATR]R	ID[ATR]
(a.) / + – – / ↓ + → + → + [+ + +]	*!			**
(b.) / + – – / ↓ + → + → + [+ – +]		*!		**
(c.) / + – – / ↓ ↓ ↓ + – – [+ – –]			$*_1*_2$!	
(d.) / + – – / ↓ + → + → + [+ – –]		**!		**
(e.) ☞ / + – – / ↓ ↓ + – → – [+ – –]			$*_1$	

Candidate (a.) violates the high-ranking feature co-occurrence constraint. Candidates (b.) and (d.) violate reciprocity. This leaves candidate (e.), the opaque candidate with no spreading to the neutral vowel to win.

(83) Opacity and Turbid Spreading

/i ɛ i/	*[+ATR, –HIGH]	RECIPROCITY	SPREAD [ATR]-R	ID[ATR]
(a.) ☞ / + − + / ↓ ↓ + − → − [+ − −]			$*_1$	*
(b.) / + − + / ↓ ↓ + → + + [+ − +]		*!	$*_2$	*
(c.) / + − + / ↓ ↓ ↓ + − + [+ − +]			$*_1*_2$!	
(d.) / + − + / ↓ ↓ + − → − [+ − +]		*!	$*_1$	*

Candidate (a.) incurs a single spread violation because of the failure of the first vowel to spread to the medial vowel. Candidates (b.) and (d.) violate reciprocity. Candidate (c.) incurs two spread violations for lack of spreading.

4.2.5.2 Interactions of SPREAD-R and SPREAD-L

So far, all constraint interactions have assumed a single harmony inducing constraint: SPREAD-R. However, when both SPREAD-R and SPREAD-L are allowed to interact, more options are available for possible winners. I assume that SPREAD-R and

Spread-L are always ranked with respect to each other such that there is always a default direction for spreading in any language. When both Spread constraints outrank ID, spreading will apply in the opposite direction, when spreading in the default direction is not possible. This is illustrated in (84) below.

(84) Interaction of Spread-R and Spread-L

/ɪ e/	*[+ATR, –High]	Rec	Spread [ATR]-R	Spread [ATR]-L	ID[ATR]
(a.) / – + / ↓ ↓ – + [– +]	*!		$*_1$	$*_2$	
(b.) / – + / ↓ ↓ – + [– –]		*!	$*_1$	$*_2$	
(c.) / – + / ↓ – → + [– –]		*!		$*_2$	*
(d.) ☞ / – + / ↓ + ← + [+ +]			$*_1$		*

In (84) the only candidate that can satisfy spreading also violates high-ranked Reciprocity. Because Spread-L outranks ID, spreading can apply in the opposite direction. In this type of language, rightward spreading is the default, but when this is not possible, leftward spreading may apply.

4.2.5.3 Additional Interactions

In the tableaux above, all candidates that include a vowel that is projected by the surface form are harmonically bounded. This is because a feature projected by its surface form violates faithfulness and cannot participate in spreading. However, it is possible for a candidate projected by its surface form to win an evaluation. This occurs if (i) the underlying feature value of the vowel is marked and cannot surface faithfully, (ii) the vowel cannot get its unmarked feature value from spreading and (iii) RECIPROCITY is ranked above ID. For example, the input /e/ in tableau (85) below cannot surface faithfully as [e] (candidate (a.)) without violating the high-ranked featural markedness constraint or projected by the underlying form but pronounced as [–ATR] [ɛ] (candidate (b.)) without violating RECIPROCITY. When RECIPROCITY outranks ID, projection from the surface form is optimal (candidate (c.)).

(85) Pronunciation-Level Projection

/e/	*[+ATR, –HIGH]	RECIPROCITY	ID[ATR]
(a.) / + / ↓ + [+]	*!		
(b.) / + / ↓ + [–]		*!	
(c.) ☞ / + / – ↑ [–]			*

Because so many conditions are required for a feature to be projected by its surface form, we expect that this representation should only occur in select forms. This expectation is borne out in the factorial typology: few languages allow projection by the pronunciation form, and only in select cases.

Another constraint interaction that applies between SPREAD and featural markedness is that a particularly marked feature will be licensed by spreading. If SPREAD outranks featural markedness, which both outrank ID, then the marked feature will appear only as a result of spreading. Underlyingly marked segments will surface unfaithfully to repair the marked feature value. This is illustrated in (86) below. Note that if RECIPROCITY is low-ranked, then the marked vowel will be transparent regardless of the ranking of SPREAD.

(86) Marked Fear Licensed by Spreading

/ɪ e/	SPREAD [ATR]R	REC	*[+ATR, –HIGH]	ID[ATR]
(a.) ☞ / – + / ↓ – → – [– –]			*	*
(b.) / – + / ↓ – → – [– +]		*!		*
(c.) / – + / ↓ ↓ – + [– +]	*!			

Candidate (b.) satisfies spreading, but violates RECIPROCITY. RECIPROCITY must be ranked lower than both Spread and featural markedness for spreading to license a marked feature value. Candidate (c.) fails to spread at all, violating the high-ranked SPREAD constraint.

4.3 Myopia and Vowel harmony

With a general account of spreading in place, I will now present the ways in which this approach is able to account for all the myopia effects discussed in Chapter 2. First, majority rules effects are ruled out through a directional constraint.

4.3.1 Majority Rules

Repeated from Chapter 2, the tableaux below illustrate how AGREE can predict majority rules spreading. With two [+ATR] vowels in the input and one [–ATR] vowel, the surface form is [+ATR], but when there are two [–ATR] vowels but only one [+ATR] vowel, the output surfaces as [–ATR]

(87) AGREE >> ID

/bɪnigi/	AGREE[ATR]	ID[ATR]	*[+ATR]	*[–ATR]
[bɪnigi]	*!		**	*
[bɪnɪgɪ]		**!		***
[binigi]		*	***	

The difference between (87) and (88) is that the number of [–ATR] vowels in the input, which translates into the number of ID violations.

(88) AGREE >> ID

/bɪnɪgi/	AGREE[ATR]	ID[ATR]	*[+ATR]	*[–ATR]
[bɪnɪgi]	*!		**	*
[binigi]		**!	***	
[bɪnɪgɪ]		*		***

With a directional constraint, majority rules cannot apply because what determines what harmonizes is the direction of spreading, and not the number of ID violations.

(89) Directional Spreading Prevents Majority Rules

/bɪnigi/	SPREAD[ATR] R	ID[ATR]	*[+ATR]	*[–ATR]
(a.) / – + + / ↓ ↓ ↓ – + + [– + +] [bɪnigi]	$*_1!*_2$(W)	(L)	** (W)	* (W)
(b.) ☞ / – + + / ↓ – → – → – [– – –] [bɪnɪgɪ]		**		***
(c.) / – + + / ↓ + ← + ← + [+ + +] [binigi]	$*_1!*_2$ (W)	* (L)	*** (W)	(L)

Candidate (a.) has no spreading, incurring two violations for lack of spreading. The vowels in candidate (c.) all share the same feature value, but the candidate violates the spread constraint because spreading occurs in the wrong direction, making it non-optimal. With directionality encoded into the constraint, it is impossible for majority rules to apply.

4.3.2 Sour Grapes Harmony

Sour grapes harmony occurs when harmony from V_1 to V_2 is prevented by the presence of a non-participating vowel V_3 that does not intervene between the two vowels. In (90) the non-high vowel /ɛ/ of the input /i ɪ ɛ/ does not participate in vowel harmony. A theory suffering from the sour grapes pathology will predict that the initial [+ATR] vowel will fail to spread to the medial [–ATR] vowel only in the presence of a non-participating final vowel: candidate (c.) or (d.) will win. But as (90) illustrates, the proposed theory of Turbid Spreading gives the correct, myopic spreading: the [+ATR] feature spreads to the medial vowel — candidate (a.).

(90) Sour Grapes and Turbid Spreading

/i ɪ ɛ/	*[+ATR, –HIGH]	RECIPROCITY	SPREAD[ATR]R		ID[ATR]
(a.) ☞ / + – – / ↓ ↓ + → + – [+ + –] [i i ɛ]				$*_2$	*
(b.) / + – – / ↓ + → + → + [+ + –] [i i ɛ]		*!			**
(c.) / + – – / ↓ ↓ ↓ + – – [+ – –] [i ɪ ɛ]			$*_1$!	$*_2$	
(d.) / + – – / ↓ ↓ + – → – [+ – –] [i ɪ ɛ]			$*_1$!		*

Candidate (a.) is the opaque candidate. Spreading occurs from left to right, from the first /i/, changing the second vowel to [i]. The second vowel fails to spread [+ATR] to the final vowel [ɛ] because in order to do so without violating reciprocity, it would violate the high-ranked inventory constraint. Candidate (b.) is the transparent candidate. Spreading stops right at the vowel [ɛ] in candidate (a.). The difference here is that a fatal reciprocity violation is incurred for [ɛ] which alters its projection, but not its pronunciation. Candidate (c.) is the disharmonic candidate with no spreading at all; it therefore fatally incurs two violations of SPREAD-R. Candidate (d.) is the sour-grapes candidate with vacuous spreading from the medial vowel. Both candidates only have one spread violation and one ID violation, but because SPREAD-R is evaluated from left-to-right, a violation at the beginning of the word is worse than a violation later in the word. Candidate (d.) is therefore fatal because of its early violation of SPREAD-R. (Without directional evaluation, (d.) ties with (a.) on the constraints present constraints, so that lower-ranked constraints can erroneously cause (d.) to win.).

4.3.3 Deletion

Another prediction that previous harmony-inducing constraints make is that if a vowel cannot undergo spreading, that vowel may delete, illustrated below.

(91) Deletion of a non-undergoer

/bina/	*[–HIGH, +ATR]	AGREE[ATR]	MAX-V	ID[ROUND]
[bina]		*!		
☞ [bin]			*	
[binæ]	*!			*

In (91), the final vowel deletes, rather than creating an AGREE violation. This is a completely unattested pattern that is avoided in Turbid Spreading, because projections may not be deleted, only changed via spreading. A deleted vowel that undergoes spreading will violate both MAX and RECIPROCITY, but is still subject to the SPREAD constraints. Deletion of a vowel after spreading will be harmonically bounded by a transparent vowel. This is illustrated in (92) below.

(92) Vowel Harmony and Deletion

/i a/	*[+ATR, –HIGH]	REC	SPREAD [ATR]-R	MAX-V	ID[ATR]
(a.) / + – / ↓ + → + [+ +] [i æ]	*!				*
(b.) / + – / ↓ + → + [+ –] [i a]		*!			*
(c.) ☞ / + – / ↓ ↓ + – [+ –] [i a]			*		
H.B. by c. (d.) / + – / ↓ ↓ + – [+ Ø] [i]			*	*!	
H.B. by b. (e.) / + – / ↓ + → + [Ø +] [i]		*!		*	

Candidate (a.) allows spreading to the blocker, fatally violating *[+ATR, –HIGH]. Candidate (b.) undergoes spreading, but the feature value at the pronunciation level does not reflect this, and (b.) therefore incurs a violation of RECIPROCITY. Candidate (c.)

satisfies RECIPROCITY, but violates spreading. Candidate (d.) deletes the final vowel, but does not spread, violating RECIPROCITY, MAX and SPREAD. Candidate (e.) spreads and deletes, violating MAX and RECIPROCITY. Candidate (c.) harmonically bounds candidate (d.) and candidate (b.) harmonically bounds candidate (e.); both deletion candidates are harmonically bounded. Therefore, deletion of a non-participating vowel is predicted to not occur under Turbid Spreading, for any ranking.

4.3.4 Epenthesis and Vowel Harmony

The present analysis of harmony assumes that epenthetic vowels may participate in harmony if the epenthetic vowel is epenthesized on the projection level. If an epenthetic vowel appears only on the surface level, it cannot participate in harmony, and it incurs an extra violation of DEP, as illustrated in (93) and (94) below.

(93) Epenthesis on the projection level: vowel participates in harmony

/ +ATR C Ø C –ATR /
↓
[+ATR] → [+ATR] →[+ATR]

[+ATR] [+ATR] [+ATR]

(94) Epenthesis on the pronunciation level: vowel transparent to harmony

/ + C Ø C – /
↓
[+ATR] → [+ATR]

[+ATR] [–ATR] [+ATR]

This analysis predicts five different types of interactions of epenthesis and vowel harmony (to be verified computationally in Chapter 5). I assume that epenthesis is driven by a constraint *CC, defined in (95) below.

(95) *CC

Assign one violation for every C in which another C immediately follows it on the pronunciation level.

The first interaction essentially trivial: is no epenthesis at all. This occurs in any language in which DEP-V outranks *CC. The second interaction occurs when the vowel is epenthesized at the pronunciation level, and never participates in harmony. The third interaction occurs when the epenthetic vowel gets its features from a neighboring vowel, but non-epenthetic vowels do not undergo harmony. The fourth interaction occurs when vowel harmony is present in the language, and all epenthetic vowels participate in harmony. The fifth interaction occurs when vowel harmony is restricted to a particular direction (e.g., left to right). In this type of language, epenthetic vowels receive a default feature except when a neighboring vowel may spread in the specified direction. For example, in a left-to-right harmony language, the epenthetic vowel will get the features from the vowel on its left, and otherwise will receive the default feature value. In the next sections, I provide examples of the four non-trivial cases of the interaction of epenthesis and vowel harmony, using data from attested languages to exemplify the predicted typology. As can be gleaned from the examples in the Appendix, the typology presented here represents a fairly cohesive account of the type of interactions that are found between epenthetic vowels and vowel harmony.

(96) Feature association with epenthesis

/iCC/	*CC	DEP-V	ID[ATR]	RECIPROCITY	*[+ATR]
(a.) ☞ / + Ø / ↓ + → + [+ +] [i i]		*			**
(b.) / + Ø / ↓ + → + [+ −] [i ɪ]		*		*!	*
(c.) / + / ↓ + [+] [i]	*!				*
(d.) / + Ø / ↓ + Ø [+ −] [i ɪ]		**!			*

4.3.4.1 Case 1: Epenthetic Vowels Transparent to Harmony: Agulis Armenian (Vaux 1998)

Many Armenian dialects undergo both backness vowel harmony and epenthesis. In this section, I describe the data from Agulis, which has backness vowel harmony, but epenthetic vowels do not participate in harmony (Vaux 1998). In (97) the suffix vowel assimilates to the backness feature of the stem.

(97) Regular Back Vowel Harmony (Vaux 1998)

a.	/ton-ar/	[tónar]	'houses'
b.	/dejz-ar/	[djézær]	'heaps'
c.	/hat^{h}s-er-am/	[hat^{h}séræm][8]	'bread-pl-intr.'

In (98), the epenthetic vowel is disharmonic with the stem vowel. Note that the /a/ in (a.) and (b.) change to [o] and [u] based on independent processes affecting final stressed vowels (and stressed vowels preceding nasals) (epenthetic vowels are in **bold**).

(98) Agulus Harmony and Epenthesis (Vaux 1998)

a.	/hrat/	[h**ə**rót]	'advice'
b.	/nʃan/	[n**ə**ʃún]	'sign
c.	/sur-ats/	[surat**ə**s]	'tomb'

Clusters are broken up with the vowel [ə], but [ə] does not participate in harmony in any way ([ə] does not trigger or undergo harmony). I propose that epenthesis in Agulus applies at the pronunciation level, making it transparent to harmony. Because epenthesis at the pronunciation level incurs two violations of DEP, but epenthesis at the projection level incurs only a single violation of DEP, the only constraints that can cause surface epenthesis to be optimal are the SPREAD constraints. Because it is impossible to satisfy both SPREAD-R and SPREAD-L simultaneously, if both spread constraints are ranked above DEP, then epenthesis will occur at the projection level.

[8] Note that low vowels do not trigger harmony in Agulus.

(99) Epenthetic vowels in Agulus

/sur-ats/ 'tomb'	*CC	SPREAD-R [BACK]	SPREAD-L [BACK]	DEP-V
(a.) / + + / ↓ + → + [+ +] [sur-ats]	*!		$*_1$	
(b.) / + + ∅ / ↓ + → + → + [+ + +] [sur-atas]			$*_1*_1$!	*
(c.) ☞ / + + ∅ / ↓ + → + ∅ [+ + –] [sur-atəs]			$*_1$	**

Candidate (a.) has no epenthesis, and violates high-ranked *CC. Candidate (b.) has epenthesis at the projection level forcing an extra violation of SPREAD-L. Candidate (c.) has epenthesis on the pronunciation level, incurring an extra violation of DEP, but because it has fewer violations of SPREAD-L, epenthesis on the pronunciation level wins. The ability to apply epenthesis at the pronunciation level solves the problem that ALIGN constraints could not account for in the interaction of epenthesis and vowel harmony. When epenthesis creates a novel locus of violation for ALIGN, this violation could be avoided by not epenthesizing a vowel, creating the pathological interaction of vowel harmony and epenthesis. While epenthesis at the projection level also incurs a novel locus of violation for SPREAD, this violation can be avoided my moving epenthesis to the pronunciation level, avoiding the pathological interaction of harmony and epenthesis.

4.3.4.2 Case 2: Epenthetic Vowels Participate in Harmony: Turkish

Turkish displays both round and back harmony, with several conditioning factors. First, only high vowels undergo round harmony; non-high round vowels are licensed only in stems, and only suffixes containing high vowels are affected by round harmony (Bakovic, 2000; Clements & Sezer, 1982; J. Cole & Kisseberth, 1994). Second, non-high vowels are opaque to round harmony, but all vowels undergo back harmony (Clements & Sezer, 1982; Erdal, 2004; Kirchner, 1993; Polgardi, 1999). Third, stems may be disharmonic with respect to both round and back vowel harmony. The (less restrictive) word initial vowel inventory is given in (100) below.

(100) Turkish (Word-Initial) Vowel Inventory (Clements & Sezer, 1982; Polgardi, 1999)

	Front		Back	
	Non-round	Round	Non-round	Round
High	i	y	ɨ	u
Non-High	e	ø	a	o

Harmonic suffixes alternate in both [BACK] as well as [ROUND] features. This is illustrated in (101) below, in which the high suffix vowel becomes [ROUND] if the stem vowel is [ROUND], and all vowels agree in [BACK].

(101) Vowel Harmony in Turkish (Clements & Sezer, 1982; Polgardi, 1999)

	Nom Sg	Gen Sg	Nom Pl	Gen Pl	Gloss
(a.)	[ip]	[ip-in]	[ip-ler]	[ip-ler-in]	'rope'
(b.)	[kɨz]	[kɨz-ɨn]	[kɨz-lar]	[kɨz-lar-ɨn]	'girl'
(c.)	[jyz]	[jyz-yn]	[jyz-ler]	[jyz-ler-in]	'face'
(d)	[pul]	[pul-un]	[pul-lar]	[pul-lar-ɨn]	'stamp'
(e)	[el]	[el-in]	[el-ler]	[el-ler-in]	'hand'
(f)	[sap]	[sap-ɨn]	[sap-lar]	[sap-lar-ɨn]	'stalk'
(g)	[køj]	[køj-yn]	[køj-ler]	[køj-ler-in]	'village'

(h) [son] [son-un] [son-lar] [son-lar-ɨn] ‘end’

The genitive singular suffix /-in/ has four allomorphs, depending on the [ROUND] and [BACK] specification of the final root vowel. The nominative plural suffix /-ler/ has only two allomorphs, front ([ler]) and back (lar), because, although round non-high vowels can appear in stems, non-high vowels do not participate in round harmony and suffixal vowels are always non-round.

Because epenthetic vowels are always high, epenthetic vowels always participate in both back and round harmony (Clements & Sezer, 1982; Kirchner, 1993). This is illustrated in (102) below.

(102) Epenthetic Vowels Participate in Vowel Harmony (Kirchner, 1993)

a. /hükm/ → hük**ü**m 'judgment'
b. /kojn/ → koj**u**n 'bosom'
c. /metn/ → met**i**n 'text'
d. /sabr/ → sab**ɨ**r 'patience'

To account for the fact that epenthetic vowels participate in harmony, I assume that epenthesis occurs at the projection level. This occurs if DEP is ranked above both spread constraints.

(103) Epenthetic vowels in Turkish

/kojn/ 'bosom'	*CC	Dep-V	Spread-R [Back]	Spread-L [Back]	ID [Back]
(a.) / + / ↓ + [+] [kojn]	*!				
(b.) ☞ / + Ø / ↓ + → + [+ +] [kojun]		*		*	
(c.) ☞ / + Ø / ↓ + Ø [+ –] [kojin]		**!			

Candidate (a.) has no epenthesis and therefore violates high-ranked *CC. Candidate (c.) has epenthesis at the pronunciation level and therefore incurs an extra violation of Dep. Candidate (b.) has epenthesis at the projection level, and incurs the fewest violations of Dep without violating *CC. The added vowel incurs an extra violation of Spread-L, but because Dep is ranked above both spread constraints, but below *CC, epenthesis is optimal at the projection level.

4.3.4.3 Case 3: Epenthetic Vowels Participate in Alternative Harmony: Karchevan

The Armenian dialect of Karchevan displays a back harmony rule (Vaux, 1995). Epenthetic vowels participate both this back harmony process as well as a round harmony process. Regular back vowel harmony in Karchevan (Vaux, 1995, 1998)

(104) Back Alternations for Non-Epenthetic vowels in Karchevan (Vaux, 1995, 1998)

a. onkh-ar ‘eyebrows’
b. æts-ær ‘goats’
c. g^{j}ørn-ær ‘sheep-pl’
d. byn-y ‘nest-dat’
e. sar-u ‘mountain-dat’

(105) Back/Round Alternations for Epenthetic vowels in Karchevan (Vaux, 1995, 1998)

	Underlying Form	Surface Form	Gloss
a.	værdn	værd**i**	‘rose-def’
b.	myrdʒym-m	myrdʒym**y**	‘ant-def’

That non-epenthetic vowels only undergo back harmony while epenthetic vowels undergo both back and round harmony can be explained in terms of an emergence-of-the-unmarked effect in which identity to the round feature outranks spreading of the round feature. If epenthetic vowels have no underlying features, then epenthetic vowels vacuously satisfy featural identity and can undergo spreading. This raises the question of why epenthetic vowels do not undergo spreading for every possible feature. While full vowel copy is common for epenthetic vowels, it is also possible for only one or two features to spread to the epenthetic vowel. I assume that these spreading processes are blocked by high-ranked constraints that determine which feature values are optimal for a given language. These constraints can be used to determine the default feature values for epenthetic vowels. For example, epenthetic vowels in Karchevan are always [+HIGH], which means that there is a high-ranked constraint[9] forcing epenthetic vowels to have this feature at the pronunciation level.

(106) Epenthetic vowels in Karchevan

/++/ myrdʒymy 'ant-def'	*CC	DEP-V	SPREAD-R [BACK]	ID [ROUND]	SPREAD-R [ROUND]
(a.) / + + / ↓ + → + [+ +] [myrdʒym]	*!				
(b.) ☞ / + + Ø / ↓ + → + → + [+ + +] [myrdʒymy]		*			
(c.) / + + Ø / ↓ ↓ + → + ∅ [+ + –] [myrdʒymi]		**!			

Candidate (a.) violates the high-ranked *CC constraint avoiding epenthesis. Candidate (b.) violates SPREAD-L constraints, but surfaces because it has fewer DEP violations than Candidate (c.)., in which epenthesis occurs only at the pronunciation level.

9 This constraint must apply only to epenthetic vowels, either through the formulation of the constraint or due to interaction of faithfulness.

4.3.4.4 Case 4: Direction-Dependent Participation in Vowel Harmony: Sesotho

In Sesotho, a southern Bantu language spreading (vowel copy) to an epenthetic vowel only occurs if there is an underlying vowel to the left of the site of epenthesis (Rose & Demuth, 2006). Otherwise, the vowel quality is determined by the nature of the consonant to its left. Ignoring consonant assimilation, this is represented by having epenthesis at the pronunciation level for all epenthesis sites at the left edge of the word, and epenthesis at the projection level for all other epenthesis sites. This is achieved when SPREAD-L is ranked above DEP and SPREAD-R is ranked below DEP. When the epenthesis site is at the left edge, the epenthetic vowel does not participate in harmony, as illustrated in (107). Otherwise, the epenthetic vowel participates in harmony, as in (108).

(107) Epenthetic vowels in Sesotho

/+/ blik 'wasp'	*CC	SPREAD-R [BACK]	DEP-V	SPREAD-L [BACK]
(a.) / – / ↓ – [–] [blik]	*!			
(b.) / ∅ – / ↓ – ← – [– –] [belik]		*!	*	
(c.) ☞ / ∅ – / ↓ ∅ – [+ –] [balik]			**	

In (107), the epenthetic vowel is to the left of the initial vowel, and therefore does not participate in vowel harmony. The case in which it does participate (candidate (b.)) violates SPREAD-L. Because non-derived vowels do not participate in harmony, high-ranked ID constraints prevent participation for non-epenthetic vowels.

(108) Epenthetic vowels in Sesotho

/–+CC/ hebru	*CC	ID[F]	SPREAD-R V	DEP-V	SPREAD-L V
(a.) / – + / ↓ ↓ – + [– +] [hebru]	*!		$*_1$		
(b.) ☞ / – ∅ + / ↓ ↓ – → – + [– – +] [heberu]			$*_1$	*	**
(c.) / – ∅ + / ↓ ↓ – ∅ + [– + +] [hebaru]			$*_1$	**!	**

In (108), the epenthetic vowel is to the right of an underlying vowel, and therefore can participate in rightward harmony. Candidate (c.) has epenthesis at the pronunciation level and therefore two violations of DEP.

The theory presented here is able to account for a wide range of interactions between epenthesis and vowel harmony, all of which are attested. It is important to note that none of the predicted languages are violations of myopia. The full factorial typology of the interaction of epenthesis and vowel harmony will be computed in Chapter 5 through the use of finite-state machines.

4.4 Dominant-Recessive Vowel Harmony

The vowel harmony systems described in this chapter are all strictly directional. However, there are cases of vowel harmony that appear to be primarily bi-directional, particularly dominant-recessive vowel harmony. In these cases, a dominant feature value (e.g., [+ATR]) spreads to the left and right. In other words, if a [+ATR] vowel is present in the input, all vowels will become [+ATR]. In these dominant-recessive languages, spreading is usually bi-directional. Because the constraints that I have posited are specifically directional, there is a question of how to account for these inherently bi-directional systems. Following previous analyses of dominant recessive harmony systems (Archangeli & Pulleyblank, 2002; Bakovic, 1999, 2000; Mahanta, 2007; Noske, 2000; Orie, 2003), I assume that dominant-recessive harmony is induced by two constraints: a constraint requiring spreading of a particular feature value e.g., SPREAD-R[+ATR], and an identity constraint preventing underlyingly dominant segments from changing their feature value (e.g., in previous analyses Max[ATR] (Archangeli & Pulleyblank, 2002; Orie, 2001, 2003), ID[+ATR] (Finley, submitted), ID[ATR] & *[–ATR] (Bakovic, 1999, 2000)).

If SPREAD-R[+ATR], SPREAD-L[+ATR] and ID[+ATR] are all ranked above ID[ATR], then harmony will always be bi-directional.

(109) Bi-Directional Harmony in Dominant-Recessive Harmony

/– + –/	SPREAD-L [+ATR]	ID [+ATR]	SPREAD-R [+ATR]	ID [ATR]
(a.) ☞ / – + – / ↓ + ← + → + [+ + +]				**
(b.) / – + – / ↓ – ← – ← – [– – –]		*!		**
(c.) / – + – / ↓ – → – → – [– – –]		*!		*
(d.) / – + – / ↓ ↓ + ← + – [+ + –]			$*_2$!	*
(e.) / – + – / ↓ – + → + [– + +]	*!			*

Note that candidate (a.) does not violate either SPREAD constraint because the [+ATR] feature spreads both to the left and the right. While, the initial vowel does not spread, no violations of SPREAD are incurred because this initial vowel is [–ATR] and not subject to the SPREAD-[+ATR] constraint.

The tableau predicts bi-directional spreading of [+ATR], but this is only because both spread constraints are ranked above ID. If SPREAD-R, for example, were ranked below ID, then the underlyingly [+ATR] vowel would only spread to the left. One interpretation is that there is nothing in principle wrong with this situation, as languages where a privative feature (e.g., [NASAL] or [ROUND]) spread the specific feature value in one particular direction. It may be possible to spread the dominant feature in a particular direction. The problem with this interpretation is that there seems to be something fundamentally different about spreading a privative feature and dominant-recessive harmony languages: dominant-recessive languages do not spread privative features and are always bi-directional.

Another problem with the present analysis is the use of specific featural identity constraints (ID[+ATR]). These constraints do not always prevent an underlyingly [+ATR] vowel from becoming [–ATR] to avoid the SPREAD constraint. If ID[+ATR] is ranked below SPREAD, then it may be better for an underlyingly [+ATR] to become [–ATR] if there is a non-participating vowel present. One way of getting around these issues is to reformulate the SPREAD[+ATR] constraint to make the constraint be evaluated in terms of the source outward, and will therefore be inherently bi-directional, as illustrated in (110) below.

(110) Spreading Outward From [+ATR]

```
/–     +     – /
    ↓
+ ←  + →  +

+      +      +
```

The constraint SPREAD[+ATR] is violated for any [+ATR] vowel at the projection level that does not spread in either direction. To rid the need of a specific faithfulness constraint (ID[+ATR]), the constraint will be formulated such that all vowels must be projected by the [+ATR] feature, if one is present underlyingly.

(111) SPREAD[+ATR]:
If a [+ATR] vowel is present in the underlying representation, then all vowels must be projected by a [+ATR] feature at the UR or PR.

This constraint requires an underlyingly [+ATR] to have its projection spread to all vowels in the lexical item. This is a very different type of constraint proposed previously in the chapter, as it is no longer local, as the projection of all vowels in the lexical item are dependent on the underlyingly [+ATR] vowel. The constraint cannot be satisfied by projection from the pronunciation level. A vowel must be projected by a [+ATR] feature as a result of spreading or by its underlying form (if it is [+ATR]).

(112) Bi-Directional Harmony in Dominant-Recessive Harmony

/– + –/	SPREAD [+ATR]	ID [ATR]
(a.) ☞ / – + – / ↓ + ← + → + [+ + +]		**
(b.) / – + – / ↓ – ← – ← – [– – –]	*!**	*
(c.) / – + – / ↓ – → – → – [– – –]	*!**	*
(d.) / – + – / ↓ ↓ + ← + – [+ + –]	$*_1$!	*
(e.) / – + – / ↓ ↓ – + → + [– + +]	$*_1$!	*

Candidate (a.) does not violate the SPREAD constraint because the underlying [+ATR] vowel spreads to the left and to the right. Candidates (b.) and (c.) each have three violations of SPREAD because none of the vowels are projected by [+ATR] despite the fact that there is a [+ATR] vowel in the underlying representation. Note that underlyingly [–ATR] vowels are expected to undergo spreading as displayed below.

(113) Bi-Directional Spread in Dominant-Recessive Harmony

/– + – –/	SPREAD [+ATR]	ID [ATR]
(a.) ☞ / – + – – / ↓ + ← + → + → + [+ + + +]		***
(b.) / – + – – / ↓ ↓ + ← + → + – [+ + + –]	$*_2$!	**

The violation of SPREAD[+ATR] in candidate (b.) is incurred because the SPREAD[+ATR] constraint is evaluated at the projection level. If an underlyingly [–ATR] vowel becomes [+ATR] on the projection, it must spread. As always, underlyingly [–ATR] vowels cannot initiate spreading.

If there are multiple [+ATR] values in the input, the SPREAD constraint can be satisfied regardless of which vowel spreads. In the tableau in (114), both candidates satisfy SPREAD[+ATR] equally.

(114) Bi-Directional Harmony in Dominant-Recessive Harmony

/– + + –/	SPREAD[+ATR]	ID[ATR]
(a.) / – + + – / ↓ (under the first +) + ← + → + → + [+ + + +]		***
(b.) / – + + – / ↓ (under the second +) + ← + → + → + [+ + + +]		***!
(c.) ☞ / – + + – / ↓ ↓ + ← + + → + [+ + + +]		**

Candidates (a.) and (b.) tie in this optimization, both satisfying SPREAD and both violating ID three times. However, because SPREAD is also satisfied by an underlyingly [+ATR] vowel that does not undergo spreading, candidate (c.) also satisfies SPREAD, but only violates ID two times.

When a non-participating vowel is present, all vowels that do not undergo [+ATR] spreading are subject to the SPREAD constraint, as demonstrated in (115) below.

(115) Bi-Directional Harmony in Dominant-Recessive Harmony

/– + + – –B/	SPREAD [+ATR]	ID [ATR]
(a.) ☞ / – + + – –B / ↓ ↓ ↓ + ← + + → + – [+ + + + –]	*$_3$	**
(b.) / – + + – –B / ↓ ↓ ↓ ↓ + ← + + – – [+ + + – –]	*$_2$!*$_3$	*

Candidate (b.) does not undergo spreading to the blocking vowel, and therefore incurs two violations of SPREAD. Even if –B did not incur a violation of SPREAD, candidate (a.) would still surface as directional evaluation prefers spreading as far as possible, and the first non-participating vowel in (b.) incurs a more severe violation of SPREAD than the violation in candidate (a.)

The non-locality of the SPREAD[+ATR] constraint has important consequences for epenthetic vowels. If an epenthetic vowel (epenthesized at the projection level) follows a blocker, that epenthetic vowel will create an extra violation for SPREAD that would otherwise not occur if no epenthesis at the projection level has occurred. However, this does not create a pathological language, as it does for other non-local constraints like ALIGN, as the epenthetic vowel can be epenthesized at the pronunciation level and avoid the violation of SPREAD.

(116) Epenthetic Vowels and Dominant-Recessive Harmony

/+ –B CC/	*[+B]	SPREAD [+ATR]	*CC	DEP	ID [ATR]
(a.) / + –B Ø / ↓ ↓ + – → – [+ – –]		$*_1*_2$!		*	
(b.) / + –B / ↓ ↓ + – [+ –]		$*_1$	*!		
(c.) ☞ / + –B Ø / ↓ ↓ + – Ø [+ – –]		$*_1$		**	

Candidate (b.) is the pathological candidate where no epenthesis occurs in order to better satisfy the SPREAD[+ATR] constraint. The only way that this candidate can surface is if *CC ranks above DEP, in which case there will be no epenthesis to begin with.

The present analysis shows potential for accounting for a wide range of cases of vowel harmony, from directional to dominant-recessive. The non-local version of the dominant-recessive constraint works to avoid pathologies because of the variety of representations available for epenthetic vowels.

4.5 Conclusions

I have provided a representational approach to vowel harmony using Turbidity Theory, Turbid Spreading. In Turbid Spreading, all features have three levels of representation: an underlying form, a projection (abstract) form and a phonetic (surface) form. These three levels interact such that spreading is initiated by an underlying form and applies through the projection level. Because the pronunciation representation need not share the same feature value as the projection level, vowels may undergo spreading abstractly, but pronounce a different feature, providing an account of transparent vowels. Because this mismatch of pronunciation and projection comes at a cost (violating a RECIPROCITY constraint), some rankings will produce transparent non-participating vowels, while other rankings will produce opaque non-participating vowels.

Because spreading occurs as a licensing (projection) relationship between two neighboring vowels, spreading occurs at a local level. This local representation of spreading makes it possible to evaluate harmony representations in parallel without violating Wilson's (2003a) myopia generalization. Because each violation of SPREAD is localized to a particular vowel, it is possible to vary the degree of violation depending on its location in the word, as in directional evaluation (Eisner, 2000).

The use of three levels of representation makes it possible to have two levels of representation for epenthesis: the projection level and the pronunciation level. These two locations for the epenthetic vowel creates a dichotomy between epenthetic vowels participating in harmony and epenthetic vowels that are transparent to harmony, predicting an attested typology of interaction of epenthesis and vowel harmony.

I have also provided an account of dominant-recessive harmony in which the presence of a particular feature value triggers bi-directional spreading. Such constraints state that spreading of a particular feature value is always bi-directional. These constraints appear to produce the correct result, however it is unclear what types of interaction these constraints induce with the standard spreading constraints. Future work will address the interaction of dominant-recessive harmony and stem-outward harmony.

The representational approach to vowel harmony based on Turbid Spreading is part of a larger research program for understanding the nature of the typology of vowel harmony processes. Several issues will be addressed in future research including parasitic harmony and interactions with consonants. For example, the representations provided in the present proposal assume only vowel-to-vowel interactions on a single feature value. However, there are many harmony processes that interact with consonants (Turkish is a prime example (Clements & Sezer, 1982), as well as the consonant interactions seen in Sesotho above (Rose & Demuth, 2006)), and many harmony processes that are dependent on multiple features, such as Yawelmani (J. Cole & Trigo, 1988) and Turkish, where only high vowels participate in round harmony (Charette & Goksel, 1998; Clements & Sezer, 1982; Kirchner, 1993; Polgardi, 1999; Underhill, 1976).

There are other issues that deserve special attention for future research. First, I assumed that deletion can only apply at the pronunciation level, but that epenthesis may apply at either the pronunciation level or the projection level. More work needs to be done to sort out exactly why there should be a difference, and whether the predictions that are made from this distinction are borne out. For example, the fact that epenthesis can apply at both the projection and the pronunciation level predicts that there should be other processes in which epenthetic vowels can be either participating or transparent to an independent phonological process (such as stress assignment) depending on the placement of the epenthetic vowel, and that this placement should be consistent throughout the language. A language with epenthetic vowels that are transparent to harmony will also have epenthetic vowels that are transparent to other processes.

Because deletion can only occur at the pronunciation level, there is a prediction that deleted vowels should be visible to all processes that apply at the projection level. This is an important issue to understand, in order to connect Turbid Spreading with previous versions of Turbidity Theory that account for compensatory lengthening and other processes that require deletion.

While there are many avenues for future research, as well as many unknowns regarding the validity of its predictions, the work presented here provides a solution for parallel evaluation of spreading candidates without predicting unattested long-distance interactions. The next chapter provides evidence for the validity of the theory of Turbid Spreading in this regard, using finite-state machines to formalize the constraints and the theory of GEN in order to produce a factorial typology of harmony languages.

Appendix I: Typology of Interactions of Epenthesis and Vowel Harmony

Language	Epenthesis/Vowel Harmony Interaction	References
Agulus (Armenian dialect spoken in Nakhichevan)	- epenthetic [ə] does not participate in back harmony	(Vaux, 1998)
Ancient Hebrew	- vowel copy only across guttural consonants	Cited in Kawahara (2007) (McCarthy 1994: 215)
Arbore (Cushitic, southern Ethiopian)	- vowel copy between preceding a laryngeal any following non-glottalized obstruent or nasal (Hayward: 71) (optional) /gile?-n-e/ → gile?ene 'we begged' - epenthetic vowels forced to assimilate to [–Low] E-harmony	(Hayward 1984, cited by Seigel, personal communication)
Barra Gaelic	- vowel copy from preceding vowel - copy vowel's back feature comes from preceding consonant (if that consonant is contrastive for [Back])	(Halle et al 2000l; Clements 1987; Ni Chiosain 1995- cited by Kawahara 2007) (Nevins, 2004; Sagey, 1987)
Brazilian Portuguese	- vowel copy between clusters involving a tap: e.g., "bruxa" (witch) becomes "burucha". - vowel copy difficult to perceive	(Nishida, pc) (Silva, Clemente and Nishida 2006)
Chuckchee	- dominant-recessive ATR harmony (could potentially be analyzed as a step-wise height harmony) - epenthetic schwa can trigger harmony	(Kenstowicz, 1979)
Crow-Hidatsa	- The epenthetic vowel is usually /i, u, a/, rather than /a, e, i, o, u/, e.g., in Crow, [bile] 'water', [bilia] 'door', [bale] 'wood', [kulushia]'take apart'. - CVRV sequences without the pattern that do not arise from CRV. - There is some debate over whether the vowels are epenthetic or original, especially in the cases outside Mississippi Valley Siouan, i.e., these Crow-Hidatsa branch cases.	(Koontz, pc)
Egyptian Arabic	- Epenthesis outside the stem harmonizes progressively with the following affixal vowel: bint-na > bintina 'our daughter' (default)	(Farwaneh pc)

	'uxt-hum > 'uxtuhum 'their sister' (harmony) ('= glottal stop) - If the affix is guttural-initial, then the epenthetic vowel is lowered: bint-ha > bintaha 'her daughter' 'uxt-ha > 'uxtaha 'her sister'	
Farsi	- vowel copy in loan words - /e/ default vowel (occurs when intervening consonants block spreading, based on place of articulation, duration, and degree of rounding of the spreading vowel)	(Shademan, 2002)
Finnish	- epenthesis of neutral [i]/[e] to break up final C's in loanwords: - in disharmonic loans, harmonic suffixes manifest - free variation across neutral vowels analyysi+kO 'analysis?' –> analyysi+ko or analyysi+kö. - Across suffixes with a neutral vowel, the disharmonic loans show free variation: Olympia+lle+kO 'to Olympia?,' Olympia+lle+ko and Olympia+lle+kö	(Välimaa-Blum, Riitta. 1999, pc)
Iraqw	- vowel copy, only across laryngeal consonants	Cited in Kawahara (2007) (Rose 1996: 77)
Japanese	- vowel copy across allophones of /h/, otherwise [ɨ]	(Kawahara 2007)
Karchevan (subdialect of Meghri)	- epenthetic [ə] does not participate in back harmony - epenthetic vowel harmony (back and round) - epenthetic harmony separate from standard vowel harmony, applies after standard vowel harmony in Vaux's rule-ordered analysis	(Vaux 1998)
Karimojong,(Eastern Nilotic)	- epenthetic vowels always [+ATR] - neutral to ATR harmony - vowel copy for within-stem epenthesis	
Kera (Chadic)	- Regular vowel harmony: Total, height, fronting and rounding. - epenthetic vowel copy	(Pearce pc) (Pearce, 2003)

	- root vowel copied if no suffix vowel, otherwise suffix vowel is copied [mirk-t-n-n] 'greet -habitual-perfective-1sg' > [mirkitnin] [mirk-t-n-u] 'greet - habitual - perfective - 3sgm' > [mirkutnu]	
Kinyarwanda	- vowel copy only across [l]	Cited in Kawahara (2007) (Uffmann, 2006)
Kolami	- vowel copy	(Zou 1991- as cited in Kawahara 2007)
Konni	- epenthetic vowel participates in ATR harmony	(Cahill 1999)
Levantine Arabic/Palestinian Arabic	- epenthetic vowels participate in round harmony (applies only to high vowels) - epenthetic vowel realized as /u/ if stem vowel is /u/ [?akil] ‘food’ [furun] ‘oven’ - epenthetic vowels must be in the harmony domain to participate: only if the epenthetic vowel is stem-internal, and the source of alternation is the stem vowel, in other words, harmony is regressive: bint# > binit# ‘girl’ ‘uxt# > ‘uxut ‘sister’ (harmony) baHr# > baHar ‘sea’ (lowering) - harmony and lowering in Levantine do not cross a morpheme boundary perhaps because of its regressive nature: zur-t-na > zuritna not *zurutna ‘you visited us’ Yu-Tlub-l-na > yuTlubilna not *yuTlubulna ‘he asks for us’ Yi-smaH-l-ha > yismaHilha not *yismaHalha ‘he allows for her, gives permission’	(Abu-Salim, 1987)
Lule Same	Lule Sami glide vowels are described as follows (from Spiik 1989): If the previous vowel is [æ], it is pronounced as [æ]. If the following vowel/diphthong is [u] or [uo], it is pronounced like the preceding	(Spiik 1989, Moren pc)

	vowel. Otherwise it is pronounced like the following vowel/diphthong. However, Moren's research on the language (i.e. field work) provides a different picture of the glide vowels in at least one dialect (Tysfjord) of Lule Sami. The "glide vowels" seem to be voiced releases, which alternate with voiceless releases depending on the morphology involved. The voiceless releases often assimilate in quality to the preceding or following consonant. The characterization of the "glide vowels" as voiced releases rather than true vowels might be supported by the fact that they do not seem to participate in the prosodic system - not even in poetry or song.	
Mandan	Vowel copy	(Koontz pc)
Maori	- only across [r]	Cited in Kawahara (2007) (Kitto 1997: 57) (Kitto & DeLacy, 1999)
Marash (Armenian dialect)	- epenthetic vowels determined by the round and back quality of preceding/following vowel	(Vaux 1998)
Marshallese	- both V epenthesis and C deletion possible in loans	(Brasington, in preparation b)
Mohawk	- leftward vowel copy across glottal stop, otherwise [e]	(Postal, 1968) (Kawahara 2007)
Old High German	?	
Rennellese	- in loans, epenthetic vowel copy, also consonant assimilation - direction of vowel copy depends on epenthesis site (medial epenthesis may be progressive or regressive)	(Brasington, in preparation)
Samoan, epenthesis in loans	- /i/ inserted after a front vowel (other strategies for a back vowel)	(Uffmann, 2006)
Sesotho	- Epenthetic vowels in loan words (data from English and Afrikaans) - vowel copy epenthesis - /a/ copied as a 'last-resort' - feature of consonant or following vowel copied instead	(Rose & Demuth, 2006)

	- /sC/ clusters—always [ɪ]	
Shona, epenthesis in loans	- assimilation to consonant higher ranked - default to /i/ - front/height harmony	(Uffmann, 2006)
Sibe	- epenthetic vowel always [+High], but participates in vowel harmony	
Sranan, epenthesis in loans	- back/round harmony - /i/ if vowel is /a/ (inert) - default to /i/ for dorsal consonants	(Uffmann, 2006)
Svarabhakti vowels in Spanish	- copy vowels of the tautosyllabic nuclear vowel	(Schmeiser, pc)
Swahili (Bantu)	- epenthetic vowels in loan words share value of height, backness and ATR from preceding vowel	(Batibo, 1996)
Tswana (Bantu)	- epenthetic vowels in loan words share value of height, backness and ATR from preceding vowel (for final V epenthesis) or following vowel (for initial V epenthesis) - non-vowel harmony epenthetic vowels surface as /a/	(Batibo 1996)
Turkish	- epenthetic vowels participate in harmony	
Tuvan	- regular harmony in language - epenthetic high vowel subject to harmony	(Harrison, 1999)
Winnebago	Winnebago (which lacks vowel harmony in general), the epenthetic vowel in obstruent + resonant clusters always agrees with the following vowel in all features, e.g., kara-, =s^aNnaN, puNruNs, naNc^aNwaN, etc. (VN = nasalized V, s^ = esh). The situation in Mandan is similar.	(Koontz pc)
Wolof	- vowel copy in a vowel harmony language	(Ka 1994)
Yalwelmani	- epenthesis participates in vowel harmony, can act as a blocker	
Yoruba	- epenthesis harmony (backness) in loans surfaces as either /i/ or /u/, and assimilate to labial consonants except full vowel copy to break up Cr clusters	Cited in (Akinlabi, 1993) (Kawahara, 2007)
Silly Greek	- epenthetic vowels participate in harmony	(van Oostendorp & Revithiadou, 2005)
Megisti Greek	- epenthetic high vowels transparent to harmony	(van Oostendorp & Revithiadou, 2005)

Additional vowel copy/echo epenthesis languages cited in Kawahara (2007) -- see Kawahara for refereneces		
Bardi	Vowel Copy	
Bedouin Arabic	Vowel Copy	
Capanahua	Vowel Copy	
Chamicuru	Vowel Copy	
Desano	Vowel Copy	
Farsi	Vowel Copy	
Fula	Vowel Copy	
Futankoore	Vowel Copy	
Gadaba	Vowel Copy	
Hebrew	Vowel Copy	
Hawaiian	Vowel Copy	(Kitto and de Lacy 1999)
Kalinga	Vowel Copy	
Kekchi	Vowel Copy	
Kolami	Vowel Copy	
Lenakel	Vowel Copy	
Mangap-Mbula	Vowel Copy	
Maga Rukai	Vowel Copy	
Makah	Vowel Copy	
Makassarese	Vowel Copy	
Mawu	Vowel Copy	
Mono	Vowel Copy	
Northern Tiwa	Vowel Copy	
Ponapean	- epenthetic vowels are [+High], but [+Round] is copied from following vowel	(Kitto & DeLacy, 1999)
Rennallese	Vowel Copy	
Selayarese	Vowel Copy	(Kitto and de Lacy 1999)
Somali	Vowel Copy	
Swahili	Vowel Copy	
Tigre	Vowel Copy	
Tojalabal	Vowel Copy	
Tunica	Vowel Copy	
Tswana	Vowel Copy	
Welsh	Vowel Copy	
Winnebego	Vowel Copy	
Yapese	Vowel Copy	
Yuhup	Vowel Copy	

Appendix II: Constraints

(117) SPREAD-R (f.)
For all non-initial vowels, for each feature value [αF] on the phonological level, assign one violation if there is not a rightward-pointing projection arroworiginating at that feature value belonging to a rightward adjacent vowel.

(118) SPREAD-L (f.)
For all non-final vowels, for each feature value [αF] on the phonological level, assign one violation if there is not a leftward-pointing projection arroworiginating at that feature value belonging to a leftward adjacent vowel.

(119) RECIPROCITY
Assign one violation for every feature value [αF] which does not have a corresponding value [αF] at the phonetic level.

(120) ID[F]
Assign one violation for every segment whose underlying form does not project the feature [F] onto that segment, whose projection comes from its pronunciation form or a neighboring segment.

(121) MAX
Assign one violation for each feature at the phonological level that has no corresponding feature at the surface level.

(122) DEP
For each feature at the phonetic level, assign one violation for each missing corresponding feature at the phonological or underlying levels.

(123) *[+ATR, –HIGH]
Assign one violation to each vowel that is [+ATR] and [–HIGH] on the pronunciation level

(124) *CC
Assign one violation for every C in which another C immediately follows it on the pronunciation level.

(125) SPREAD[+ATR]:
If a [+ATR] vowel is present in the underlying representation, then all vowels must be projected by a [+ATR] feature at the UR or PR.

Chapter 5: Computational Methods for Finding Pathological Typologies

5.1 Introduction

In this chapter, I present the methodology and results of a computational analysis of typological predictions from analyses in Optimality Theory. The constraints and representations used in Turbid Spreading are translated into finite-state machines, which are fed into the Contenders Algorithm for determining optimal outputs (Riggle, 2004). These outputs were fed into a program written by Jason Riggle (personal communication), to compute factorial typologies using algorithms based on Elementary Ranking Conditions (ERC's) (Prince, 2002).

This chapter is organized into three parts. First, I present the Contenders Algorithm and explain how it computes a finite set of possible optimal candidates from an infinite candidate set, using a simple toy example with CV strings. Second, I describe the finite state machines for Turbid Spreading that were implemented for the Contenders Algorithm, and how a complete list of inputs was created for up to four vowels. Finally, I will present the results of the factorial typology predicted by Turbid Spreading. The restricted factorial typology demonstrates that Turbid Spreading is free of typological pathologies.

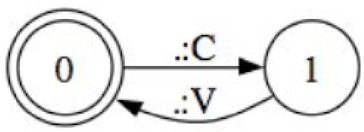
5.2 Contenders Algorithm

Riggle's (2004) algorithm uses finite-state techniques to find possibly-optimal outputs for an infinite candidate set. In order to compute constraint violations, both GEN and the constraints in CON must be represented in terms of a finite state transducer. A finite state transducer is a finite state machine with an input string as well as an output string and is therefore able to accept strings, making it possible to implement a formal language that creates input-output pairs. Finite-state machines are able to represent an infinite number of possible candidates in a finite graph (each of a finite length) because these machines provide a mechanism for producing candidates, rather than listing every possible candidate.

For example, the extremely simple machine below creates sequences of CV syllables from any input. If we think of the machine below as GEN, which represents a function that creates possible outputs from inputs, the first element in the transition is the input, and the second element is the corresponding output (separated by a colon ':'). The dot '.' represents any possible input. The arc .:C represents an input to output pair in which the first element is able to surface as a consonant C. For this machine, it does not matter what the input is, GEN will produce an unbounded set of candidates, all of CV strings.

The machine starts at state 0, and moves to state 1 after producing a C, and back to state 0 after producing a V. A string generated by the machine is the result of any number of state transitions *ending in a legal end state*, here, only the state 0 (double-line circle). Because there are an infinite number of ways to produce a valid string, there are infinitely many possible strings. However, since each string must end on a legal end state, all strings are of finite length. The strings are restricted to be either nothing, or any sequence of CV (CV, CVCV, CVCVCVCV etc.). With just two states (0 and 1) and two transitions (0→1 and 1→0), this finite-state machine can represent strings of unbounded length. Each transition from state 0 to state 1 is referred to as an arc. For machines based on constraints, each arc may assign a different penalty or weight. Because GEN assigns no penalties, arcs are of equal weight.

(126) Simple Finite-State Machine

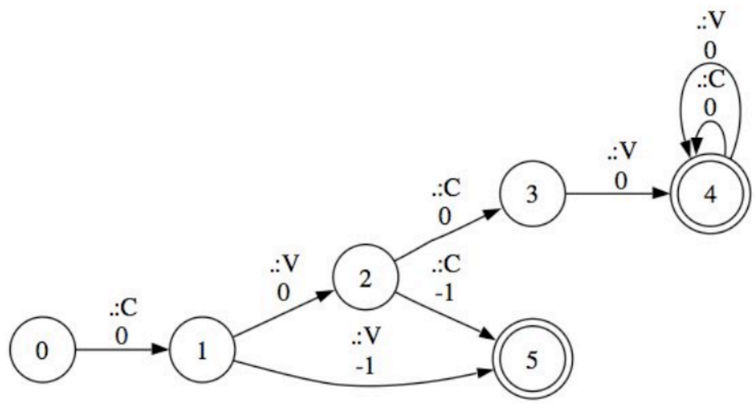


The use of finite representations of infinite sets of strings has important consequences for Optimality Theory. As long as GEN can be represented as a finite-state machine, it is possible to represent the infinite candidate set in terms of a single finite computation. This fact is important for easing the concern that many linguists have about the infinite candidate set proposed in classic Optimality Theory (Prince and Smolensky 1993/2004): how can a human being store/process an infinite candidate set in a finite amount of time and space? While computing an infinite candidate set may appear to be overwhelming, when posed in terms of finite-state machine, such computations become quite doable. The infinite candidate set can be thought of analogous to phrase structure grammars that can produce an infinite number of sentences with finite means. We do not memorize all possible sentences or words in our language, but instead have a way of generating these possible sentences and words. The candidate set is similar— infinite by means of a finite generation system. However, there is an important difference between sentence construction and candidate construction and evaluation. If the *entire candidate set* needs to be actually generated to compute a single output from the grammar, that would require infinitely many transitions in total. In sentence generation, a finite set of phrase generation rules generates an infinite number of possible sentenes, but in the OT case two steps are required: (1) a finite machine must encode the entire candidate set, but in addition, (2) the computation of the optimal output for an input must be computed with a finite number of operations on the finite machine encoding the entire candidate set (without having to use the machine to actually generate the whole candidate set).

Imagine that the very small machine presented in (126) was GEN. This machine generates only CV strings, meaning that all candidates would be CV strings of varying lengths. These strings would be evaluated for a given input in terms of constraints. To evaluate the candidates produced by GEN, the constraints must also be formulated in terms of finite-state machines. Returning to our toy example with CV sequences, imagine that there is a markedness constraint penalizing sub-minimal length, so any string less than CVCV would get a violation. There could also be faithfulness constraints for adding C's and V's. Because constraints must all be represented in terms of a finite-state machine, each of these the machines for each of these constraints must be added to the grammar. Now, there are three finite-state machines: GEN and two constraints (MinLength and DEP).

Finite-state machines for constraints work differently than GEN machines. For each arc of a constraint machine, a cost is assigned. Because this cost is equivalent to a constraint violation, all costs are either 0 or a negative integer (typically –1). Each path through a constraint machine will have a cost associated with it. For the MinLength constraint in (127), the cost of a CV output is –1. The first arc produces a C, with no cost, but the second arc, produces a V with the cost of –1. It is also possible for the second arc to produce a V with a cost of 0, as long as it is not the final element in the string (only states that are marked with a double line can end a string). Because MinLength is a markedness constraint, it only evaluates the output form, and the value for the input will never matter, and is marked with a '.' symbol.

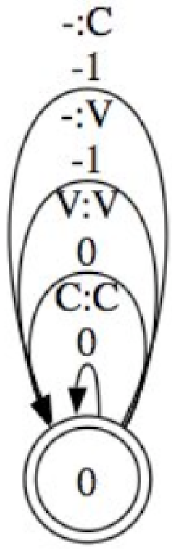
(127) MinLength Constraint



Any path with cost 0 must pass through more nodes than a string with a cost of –1. This is irrelevant. The number of nodes that a given candidate passes through is not considered in terms of the cost: only the arcs contribute to the cost (in the values they assign to the transition), corresponding to constraint violations.

The MinLength constraint machine in (127) has an infinite number of 0-cost paths. However, when all constraints are combined and a single input is evaluated, there will only be a finite set of contenders. For example, if we add the DEP constraint in (128) below to the grammar, and evaluate candidates based on the input /CV/ there are many ways traverse the grammar, but each will have a different violation profile. Because epenthetic vowels have no input representation, a '-' symbol used to indicate insertion, and no representation in the input. Vowel insertion is represented as [-:V] and consonant insertion is represented as [-:C]. Each violate DEP once.

(128) DEP Constraint



The first step of the Contenders Algorithm is to take these three machines and combine them into a single machine, making it possible to perform OT evaluations of possible outputs for individual inputs. The combined machine may be thought of in terms of a 'grammar' machine. The machine includes all the constraints and a method for generating candidates (GEN) from a given input (specified by the user). There is no specific ranking of the constraints, as the Contenders Algorithm is searching for possible candidates under any ranking.

In order to generate a set of paths through the machine, the machine must have an input, which serves as the input into the the Contenders Algorithm. For example, the input /CV/ will generate any number of CV sequences, with CV being fully faithful, but epenthetic CV's (CVCV, CVCVCV, etc.) are all possible. The representation for the fully-faithful candidate will be: CV: CV. One possible representation for an epenthetic CV might be the following: CV--: CVCV.

Each input-output pair produced by GEN has a cost associated with it, when put through the combined machine. If there are two possible paths through the machine for a given input-output pair, the lowest cost path is chosen. The combined machine will provide the constraint violation profile for any candidate produced by GEN: the cost of traversing the machine from start to finish for each input-output pair. The Contenders Algorithm compares violation profiles for given constraints and candidates, making it possible to predict which violation profiles (candidates) are likely to win (i.e., which candidates are contenders).

The basic idea of the Contenders Algorithm is that each path through a weighted machine (i.e., a machine that has costs associated with different arcs through the machine, constraint violations) has a cost associated with it. The job of the Contenders Algorithm is to find the cheapest, least costly paths through the machine. This is done by storing the costs associated with visiting each node in the machine for each node of the machine that evaluates a particular input-output pair (the grammar is the combination of GEN, and CON). For example, the cost of traversing the MinLength constraint in (127) above is 0 if the output is CVCV or longer, but –1 if it is shorter than CVCV. The cheapest paths through the machine — with cost 0 — are those corresponding to any output of CVCV or longer. Note that it is impossible to generate a string such as CVCVVVVV because the final state in GEN requires any V to be immediately preceeded by a C. While MinLength generates CVCVVVVV-type strings, the combined machine only generates the intersect of generable paths in all machines. Strings like CVCVVVVV will be ruled out by GEN in the combined machine.

The combined machine stores the cost for each constraint in an ordered n-tuples, depending on the number of constraints present. If, in our example there is DEP and MinLength, the violation profile will be an ordered pair. If we assume that the first member of the ordered pair is the violation profile for MinLength and the second member of the ordered pair is the violation profile for DEP (this order is arbitrary, as no ranking of constraints is specified in the Contenders Algorithm), the candidate [CVCV] for the input /CV/ (CV --: CVCV) has the violation profile of (0, –2) because it satisfies the MinLength constraint, but violates DEP twice. The faithful candidate CV: CV satisfies DEP but violates the MinLength constraint, and has the violation profile (–1, 0). Notice that there are other possible candidates such as CV- - - -: CVCV, which satisfies MinLength but violates DEP four times. Such candidates will be discarded by the Contenders Algorithm because there is no ranking for which a candidate with the violation profile of (0, –4) will beat the candidate ([CVCV]) with a violation profile (0, –2). In this grammar, unbounded epenthesis is harmonically bounded. By keeping track of the cost for each path through the machine, the Contenders Algorithm is able to decide which paths produce possible winners. The output of the Contenders Algorithm is a list of candidates (input-output pairs) and their constraint violations.

This simple example of CV syllables represents how computational mechanisms can be used to find the candidates that are not harmonically bounded. The Contenders Algorithm works for any number of constraints as long as the constraints are represented in terms of finite-state machines. In the next section, I demonstrate how the theory of Turbid Spreading can be represented in terms of finite-state machines so that the

Contenders Algorithm can be used, along with other tools, to find the factorial typology that the theory predicts.

5.3 Turbid Spreading in Finite State Machines

The approach described above for strings of CV's can also be applied to Turbid Spreading. The first step in translating the Theory of Turbid Spreading into finite-state machines is to create a useable, but transparent, code to represent the relationship between the underlying form, projection level and pronunciation level. The second step is to translate all the constraints and GEN into finite state machines. The third step involves creating a list of inputs. Our list contains all possible inputs up to four vowels (without epenthesis). The final step is to run the Contenders Algorithm for each input on the Turbid Spreading grammar.

5.3.1 Representations

Because the representations in Turbid Spreading have three levels, all dependent on each other, the system for representing input and output pairs must be slightly more complex than the representations found in the example above, as well as in Riggle (2004). The format of the representation was modified in order to translate the three levels of representation into a single linear encoding for use with computer programs. Arrows were also removed (and replaced with alphabetic symbols for where the projection representation), which are also not easily translatable into the code used by Contenders Algorithm and replaced them with alphabetic representations such as P for projection. The system for representing these variables is described in the table in (129) below.

(129) Symbols for Representing Turbid Spreading

Symbol in Contenders Algorithm	Representation/Turbid Spreading Output
U	Projected by Underlying Form ↓
R	Projected by Vowel to Right ←
L	Projected by Vowel to Left →
P	Projected by Pronunciation ↑
+	[+F]
–F	[–F]
–B	Marked vowel (harmony blocker) with feature [–F]
+B	Marked vowel (harmony blocker) with feature [+F]
-	No representation: epenthesis has applied Ø/0
x	No Representation: deletion has applied
.	Placeholder for all possible representations (any representation above may fit)
:	Transition from levels of representation: UR : PR : SR

The three levels of representation are written on a single line. In terms of triples, with each level separated by a colon ':'. A full triple is of the form: underlying form (UR): projection level (PR): surface form (SR) (UR:PR:SR). The underlying form is written in terms of features: /+–F+B/. The feature B is a placeholder for an additional feature value that is marked when it bears the + harmony feature. For example, B can stand for a [–High] vowel that is marked when it is [+ATR]. The projection level is represented in terms of features plus an additional notation for the source of the projection. For example, a vowel that is projected by [+F] from the right, is written as +R. The pronunciation level is represented in terms of feature values: +, –F, +B, –B. The pictorial representation in (130) below is written as: [+–F+: +U+U–FL: + –F–F] with ':' separating each level.

(130) [+–F+: +U+U–FL: + –F–F]

/[+ATR]	[–ATR]		[+ATR]/	Underlying Form
↓	↓			
[+ATR]	[–ATR]	→	[–ATR]	Projection/Phonological Level
[+ATR]	[–ATR]		[–ATR]	Pronunciation/Surface Level

The single-line translation of the above pictorial representation makes it possible for a simple computer program to read the representations of Turbid Spreading.

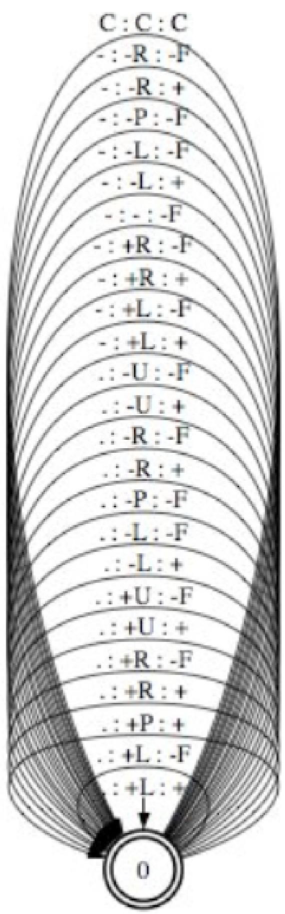
5.3.2 Finite-State Machines

To demonstrate how the finite-state machines operate, I will present two case studies, rather than go through each arc of each machine. The first case study will be for one transparent candidate: [+ –F –B : +U +L +L: + + –F]. In this candidate, the input is /+ –F –B/, the projection is +U +L +L, indicating spreading from the left to the right through the non-participating vowel. The pronunciation is + + –F indicating no overt spreading to the non-participating vowel. The second case study will be for an epenthetic vowel that undergoes harmony: [C - C +: C +R C +U : C + C +]. The underlying form of has a consonant cluster and a vowel with the feature [+]. The projection level has an epenthetic vowel that is projected by the underlying vowel (on the right). The pronunciation level has the cluster broken up by the epenthetic vowel, whose feature matches the right-most underlying vowel.

5.3.2.1 GEN

To make the computation simpler, GEN was divided into two machines: GEN for projection level and GEN for the pronunciation level. The pronunciation level GEN is fairly simple. It allows all projection level representations to be pronounced with either a [+] feature or a [–] feature value. The only exceptions are that consonants project and pronounce a [consonantal]=C feature, and any vowel projected by its pronunciation has to match feature values. For example, if a vowel is projected by [–ATR] at the pronunciation level, both the projection and the pronunciation level must be [–ATR].

(131) GEN-Pronunciation Finite-State Machine



The pronunciation level GEN has just one state because it only governs the relationship between the pronunciation and the projection. There are no constraints on the underlying form, as the pronunciation level is not governed by the underlying form.

The candidate [+ –F –B : +U +L +L: + + –F] is generated by the pronunciation level GEN as there is a state relating any input to each of the relations. The first vowel is generated by the arc [. : +U : +], the second vowel by the arc [. : +L : +] and the third vowel by the arc [. : +L : –F].

The candidate [C - C +: C +R C +U : C + C +] is generated by the the pronunciation level GEN as there is a state relating any input to each of the relations. Both consonants are generated by the arc[C:C:C], the epenthetic vowel is generated by the arc [.:+R:+] and the final vowel is generated by the arc [.:+U:+].

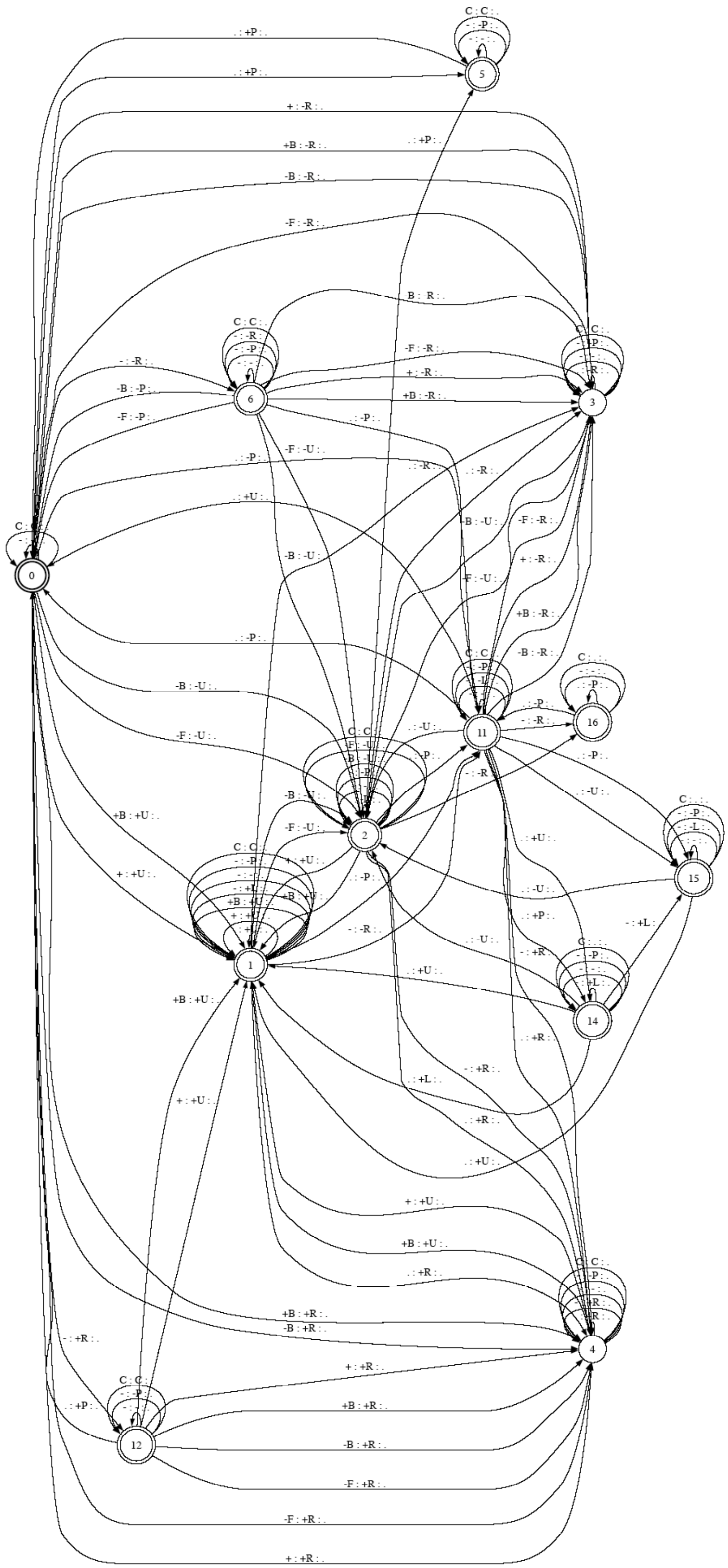
The projection-level GEN is more complicated. Most all of the restrictions on GEN (repeated in (132) below from Chapter 4) are instantiated at this level. However, the restriction that a vowel projected by its pronunciation form must share the same pronunciation value as the projection is instantiated in GEN for the pronunciation level. If a vowel is projected by the pronunciation level (e.g., +P, –P), the pronunciation level must match the projection level. GEN Pronunciation does not generate inputs with +P in the projection but –F in the pronunciation; only +P : + and –P: –F.

(132) Restrictions on GEN

a. Feature values on both sides of projection arrow must match
b. All underlying feature values projected by one and only one element: underlying form, surface form, projection level
c. The initiator of spreading must be projected by its underlying feature value
d. Deletion occurs at the pronunciation level only
e. Epenthesis occurs at the pronunciation level or the projection level

The first vowel in a word cannot be projected by the vowel to its left (because such a vowel does not exist). The first vowel always projects P, R or U. If the first vowel projects a +R, then the feature value of the following vowel must be either a +R or a +U. If the first vowel is a +U, then the following vowel can either be a +L any P or any R (and if it is –U, the next vowel can be –L, P or R). If the following vowel is an R, it follows the same route as an initial vowel with an R projection. If the initial vowel is a P, then the next vowel must be a U, R or P. However, if the vowel following the P is epenthetic (encoded by a null at the underlying form), then that vowel may project an L. This serves as an exception to the generalization that a vowel must be projected by its underlying form (U) in order to initiate spreading; a vowel projected by a P may only spread its feature to an epenthetic vowel.

(133) GEN-Projection Finite-State Machine



The restriction that feature values on both sides of the projection ‘arrows’ must match is instantiated such that if a vowel is projected by +U, the underlying form is also +, and likewise for –U. If a vowel is projected by +R, then the following vowel must be projected by +U or +R, and likewise for –R.

The restriction that an underlyingly present vowel must be projected by one and only one location is instantiated by making it impossible for any individual segment to be projected by more than one element. GEN does not generate segment triplets for which there is more than one value for the projection, or if there is no value for the projection. The only time a null representation is generateed at the pronunciation level is if the underlying form is also null (an epenthetic vowel).

The restriction that the initiator for spreading must be an underlying form is instantiating by restricting when a vowel can be projected by the vowel to its left and restricting the valid end states of leftwards spreading. A vowel can only be projected by +L if the preceding vowel is +U (and likewise for –L). For example, when a vowel is projected by –U, GEN moves into a state whereby the following vowel may be projected by –U, +P, –P, or by –L. The only states from which a vowel can be projected by –L is following a –U vowel or an epenthetic vowel. The first vowel cannot be projected by +L or –L unless there is an epenthetic vowel preceding the first underlyingly present vowel. If a vowel is projected by +R or –R, there must eventually be a vowel projected by +U or –U, respectively to have initiated the leftwards spreading. For example, if the machine reads –R, it will move to state 4, which is not a valid ending state. In order to move into a valid final state, the machine must read a vowel projected by –U. From state 4, the machine moves to state 2, a valid ending state. This prevents leftward spreading without a valid trigger.

The restriction that deletion can only occur at the projection level is instantiated such that the machine cannot generate any string in which there is a feature value at the underlying form, but a null representation at the projection level. The only deletion that can occur is at the pronunciation level such that a vowel has an underlying form, a projection representation but a null representation for the pronunciation level.

Epenthetic vowels are represented such that either a null representation or a projection value can appear at the projection level. If a null representation appears in the underlying form, there is no restriction as to whether there needs to be a representation at the projection level.

The candidate [+ –F –B : +U +L +L: + + –F] is generated by the projection level GEN as there is a state relating all of the changes from the first vowel to the last. The first vowel is represented by the arc [+: +U: .] from state 0 to state 1. The second and third vowels are each represented by the arc [. : +L : .] from state 1 to state 1. Because state 1 is a valid final state, the candidate [+ –F –B : +U +L +L: + + –F] is a valid string.

The candidate [C - C +: C +R C +U : C + C +] is generated by the projection level GEN as there is a state relating all of the changes from the first vowel to the last. The first consonant is generated by the arc[C:C:C] at state 0, the epenthetic vowel is generated by the arc [-:+R:.] from state 0 to state 12. The second consonant is generated by an the arc [C:C:C] from state 12 to state 12. The final vowel is generated by the arc from state 12 to state 1 [+:+U:.].

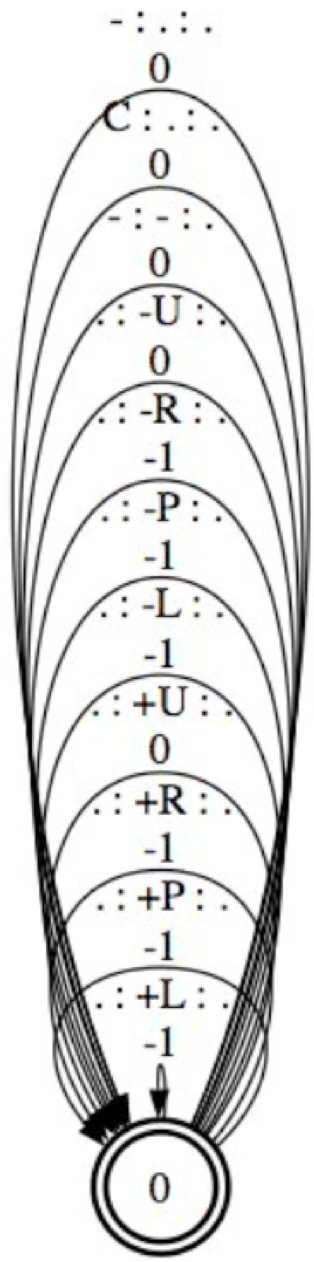
5.3.2.2 Constraints

Each constraint took the form of a finite-state machine. ID, *B, and Reciprocity are all relatively straightforward. However, Spread is more complex because it involves multiple loci for violation, plus a directional evaluation.

5.3.2.3 ID

ID[F] is violated once for every vowel that is not projected by its underlying form. ID simply goes through the projection level, and any vowel that has an underlying form, but is not marked with a U gets a violation. The requirement that the vowel must have an underlying form comes from the principle of Turbid Spreading that epenthesized vowels do not violate ID (Chapter 4.2.4.3). While the representation [.:–L:.] could incur a violation by an epenthetic vowel, the representation [-:.:.] for all epenthetic vowels incurs no violations. Because the CONTENDERS Algorithm counts the cheapest path when multiple paths are possible, all epenthetic vowels will incur no violations for ID.

(134) ID Finite-State Machine



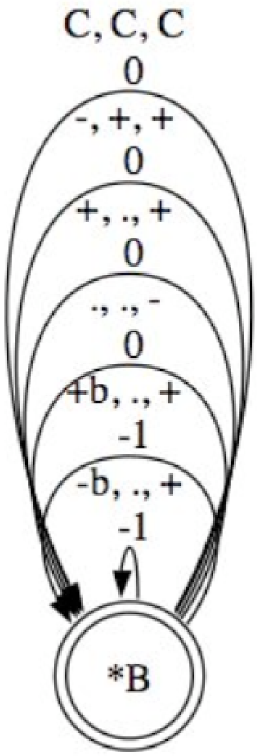
The candidate [+ –F –B : +U +L +L: + + –F] is represented by three arcs. The first vowel is represented by the arc [. : +U : . / 0], the second vowel is represented by the arc [. : +L : . / –1], and the third vowel is represented by the arc [. : +L : . / –1]. This candidate receives two violations of ID[F].

The candidate [C - C +: C +R C +U : C + C +] is generated by three different arcs. Both consonants are generated by the arc[C:.:./0] at state 0, the epenthetic vowel is generated by the arc [-:-:./0]. The final vowel is generated by the arc [.:+U:./0]. There are no violations of ID[F], as epenthetic vowels do not violate ID.

5.3.2.4 *B

*B is a placeholder for a featural markedness constraint (e.g., [–HIGH, +ATR]), and is violated for any vowel that has a B in the input (UR) and a + in the output (SR) (e.g., a [–HIGH] feature in the input and a [+ATR] feature in the output). This version of featural markedness is a simplification because it assumes that no vowels may lose their /B/ specification from the input to the output. This is a simplification because vowels can (and do) change their secondary feature value in order to undergo harmony. This process is called 're-pairing' (Bakovic 2000). Allowing changes in the B feature and providing the possibility for re-pairing is an issue for future research. However, I do not anticipate that such an addition would pose any problems for the typology of vowel harmony that Turbid Spreading predicts because allowing a vowel to change its secondary feature to undergo harmony should only increase the typology to include these languages, which are attested.

(135) *B Finite-State Machine



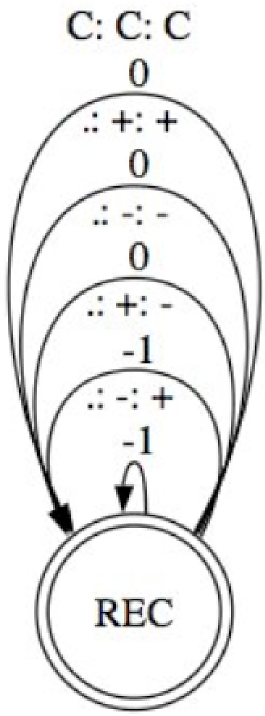
The vowels of the candidate [+ –F –B : +U +L +L: + + –F] are generated by the arc [+:.:+/0] for the first two vowels, and [. : . : – / 0] for the final vowel, meaning that this candidate does not violate *B.

The candidate [C - C +: C +R C +U : C + C +] is generated by three different arcs. Both consonants are generated by the arc[C:.:./0], the epenthetic vowel is generated by the arc [-:+:+/0]. The final vowel is generated by the arc [+:.:+0]. There are no violations of *B, as consonants and the vowels do not bear the +B feature.

5.3.2.5 Reciprocity

The Reciprocity constraint is violated whenever the feature values at the projection and the pronunciation level are not the same. This machine simply goes through the pronunciation level, and searches for a match at the projection. If the pronunciation is [+], the projection must be +U, +L or +R; if the pronunciation is a null symbol, the projection must also be a null symbol (this is how deletion violates reciprocity). I use + at the projection level as a shorthand for all values of + (+U, +R, +L, +P), and likewise for – at the projection level (–U, –R, –L, –P).

(136) RECIPROCITY Finite-State Machine



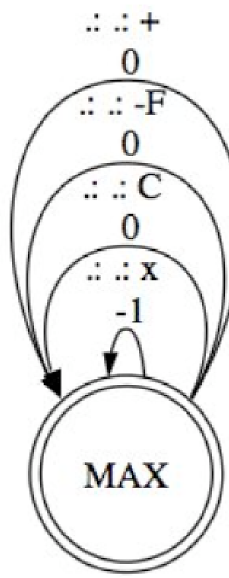
The candidate [+ –F –B : +U +L +L: + + –F] is generated by two different arcs. The first two vowels are each represented by the arc [. : + : + / 0], and the third vowel is represented by the arc [. : + : – / –1]. This candidate receives a single violation of REC.

Both consonants in the candidate [C - C +: C +R C +U : C + C +] are generated by the arc[C:.:./0], and both vowels are generated by the arc [.:+:+]. There are no violations of REC.

5.3.2.6 MAX

MAX is the constraint that is violated by deletion, represented by a null symbol in the pronunciation level. The MAX constraint simply assigns a violation if the null symbol is present in the pronunciation.

(137) MAX Finite-State Machine



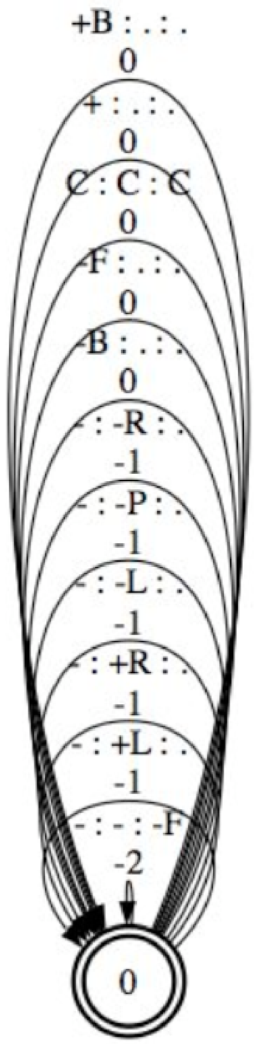
The candidate [+ –F –B : +U +L +L: + + –F] is generated by two different arcs. The first two vowels are each represented by the arc [. : . : + / 0], and the third vowel is represented by the arc [. : + : – / 0]. This candidate receives no violations of MAX, as this candidate does not delete any vowels.

Both consonants in the candidate [C - C +: C +R C +U : C + C +] are generated by the arc [.:.:C/0] and both vowels are represented by the arc [. : . : + / 0] This candidate receives no violations of MAX, as this candidate does not delete any vowels.

5.3.2.7 DEP

DEP is the constraint that is violated by epenthesis, represented by a null symbol in underlying form. The DEP constraint looks for any null symbol in the underlying form and assigns a violation for each feature value that appears on the projection and pronunciation levels. If a feature value (i.e., no null symbol) appears at the pronunciation level, a violation is assigned; if a feature value appears at the projection level, another violation is assigned. Epenthesis at the pronunciation level incurs two violations of DEP, but epenthesis at the projection level only incurs one violation.

(138) DEP Finite-State Machine



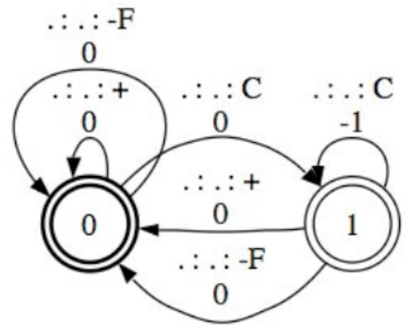
The candidate [+ –F –B : +U +L +L: + + –F] is generated by three arcs. The first vowel is generated by the arc [+ : . : . / 0], the second vowel is generated by the arc [–F : . : . / 0] and the third vowel is generated by the arc [–B : . : . / 0]. This candidate receives no violations of DEP, as there are no epenthetic vowels.

Both consonants in the candidate [C - C +: C +R C +U : C + C +] are generated by the arc [C:C:C/0]. The epenthetic vowel is generated by the arc [-:+R:./–1] and the final vowel is represented by [+ : . : . / 0] This candidate receives one violation of DEP, as the epenthetic vowel is epenthesized at the projection level, incurring one violation of DEP.

5.3.2.8 *CC

I assume that epenthesis is driven by the markedness constraint *CC. This constraint scans the pronunciation level for two consonants in a row, and assigns a violation for every pair of consonants. Unlike previous constraints, *CC requires two states. This is because *CC requires two consecutive consonants. When there is one C, it moves to a second state, which creates the potential for a violation to be incurred if another C is found immediately following the first C. Every time the machine reads a C, it moves to a state where a violation could be incurred if the next element is a C. If the next element is not a C, the machine moves back to the ‘safe’ state and will not move out of this state until another C is found.

(139) *CC Finite-State Machine



The candidate [+ –F –B : +U +L +L: + + –F] is generated by three arcs. The first two vowels are each generated by the arc [. : . : + / 0], and the third vowel is generated by the arc [. : . : –F / 0]. This candidate receives no violations of *CC, as there are no consonant clusters.

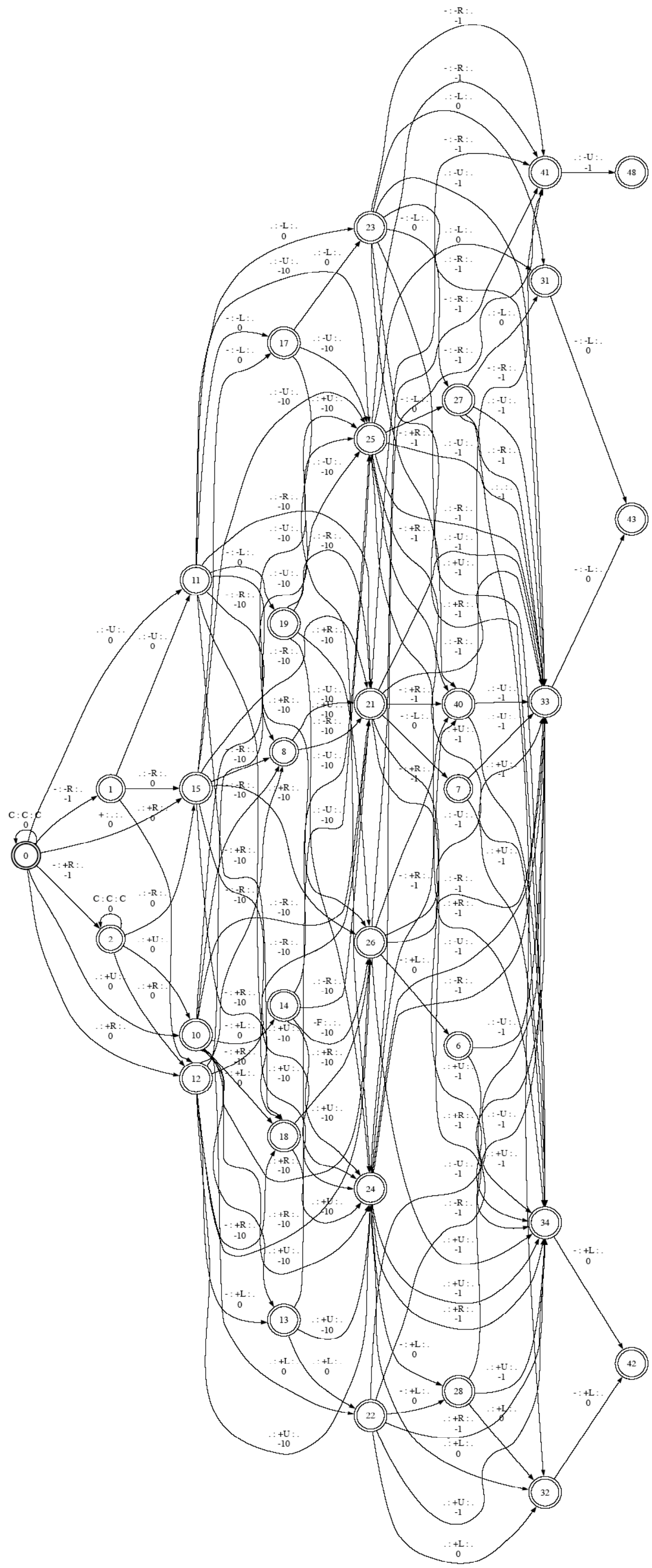
The first consonant in the candidate [C - C +: C +R C +U : C + C +] is generated by the arc [C:C:C/0] from state 0 to state 1. The epenthetic vowel is generated by the arc [.:.:+/0] from state 1 to state 0. The second consonant is generated by the arc [C:C:C/0] from state 0 to state 1. The final vowel is generated by the arc [.:.:+/0] from state 1 to state 0. Because the epenthetic vowel intervenes between the two consonants, there are no violations of *CC.

5.3.2.9 SPREAD-R

SPREAD-R can only be satisfied if a vowel projects an L. Violations for SPREAD-R are assigned directionally such that a violation on the first vowel is more severe than violations later in the word. In order to prevent 'gang' effects, violations are assigned exponentially such that for a three-vowel input, violation on the first vowel incurs 10 violations, while a violation on the second vowel incurs only 1 violation. Because the first vowel cannot project a vowel to its left, it automatically satisfies SPREAD-R. Because the source of spreading must project a U, for any initial vowel that does not project U the second vowel will automatically incur 10 violations of SPREAD-R. If the third vowel does not satisfy SPREAD-R, it will incur 1 violation. The machine keeps track of the position of the vowel in the word and also the potential to satisfy the constraint (e.g., a U projection). Epenthetic vowels violate SPREAD-R if they do not have an L projection (or no projection). The violation profile is such that epenthesis before the initial vowel incurs 1 violation, epenthesis after the initial vowel can incur 10 violations, and after the second vowel incurs 1 violation and epenthesis after the final vowel incurs no violations[10].

[10] A separate version of both SPREAD-R and SPREAD-L were constructed without allowing for epenthetic vowels. These versions of the constraints accommodated inputs up to four vowels.

(140) SPREAD-R finite-state machine



The numbering system on the arcs in the SPREAD constraints works to encode the position of the vowel. Numbers less than 10 encode vowels epenthesized before the first vowel. Numbers 10-19 encode the first vowel, 20-29 the second vowel, and 30-39 the third vowel, when possible. Several C:C:C and -:-:. arcs generating consonants and epenthetic vowels were removed in order to make the diagram more legible. However, all relevant arcs for the case studies can be seen.

The first state of SPREAD-R distinguishes between possible and non-possible initiators of spreading. Vowels that are projected by +U or –U each go to a separate state where it is possible to satisfy SPREAD (state 10 and 11). Vowels that are projected by anything else go to a state where the next vowel will automatically receive 10 violations of SPREAD. From state 10 and 11, if the vowel is projected by +R or –R, no violation is assigned, and the machine moves to a state where it is possible to satisfy spreading again. If the third vowel also projected by +R or –R respectively, the state moves to a state where no violations are assigned. If, from state 10 or 11, the vowel is projected by +U or –U, 10 violations are assigned, and the machine moves to a state where the third vowel could satisfy spreading. If the second vowel is projected by P or R, then it is impossible for the third vowel to satisfy spreading, so the machine assigns 10 violations and moves to a state where it is impossible to satisfy spreading by the third vowel, where it will receive 1 violation on the final transition. If the first vowel projects P or R, but if the second vowel projects a U, 10 violation is assigned but the machine moves to a state where it is possible to satisfy SPREAD on the transition from the second to the third vowel.

The candidate [+ –F –B : +U +L +L: + + –F] is generated by three arcs. The first vowel is generated by the arc from state 0 to state 10 [. : +U : . / 0], the second vowel is generated by the arc from state 10 to state 22 [. : +L . / 0] and the third vowel is generated by the arc [. : +L : . / 0] from state 22 to state 32. This candidate receives no violations of SPREAD-R, as this candidate undergoes full left-to-right spreading.

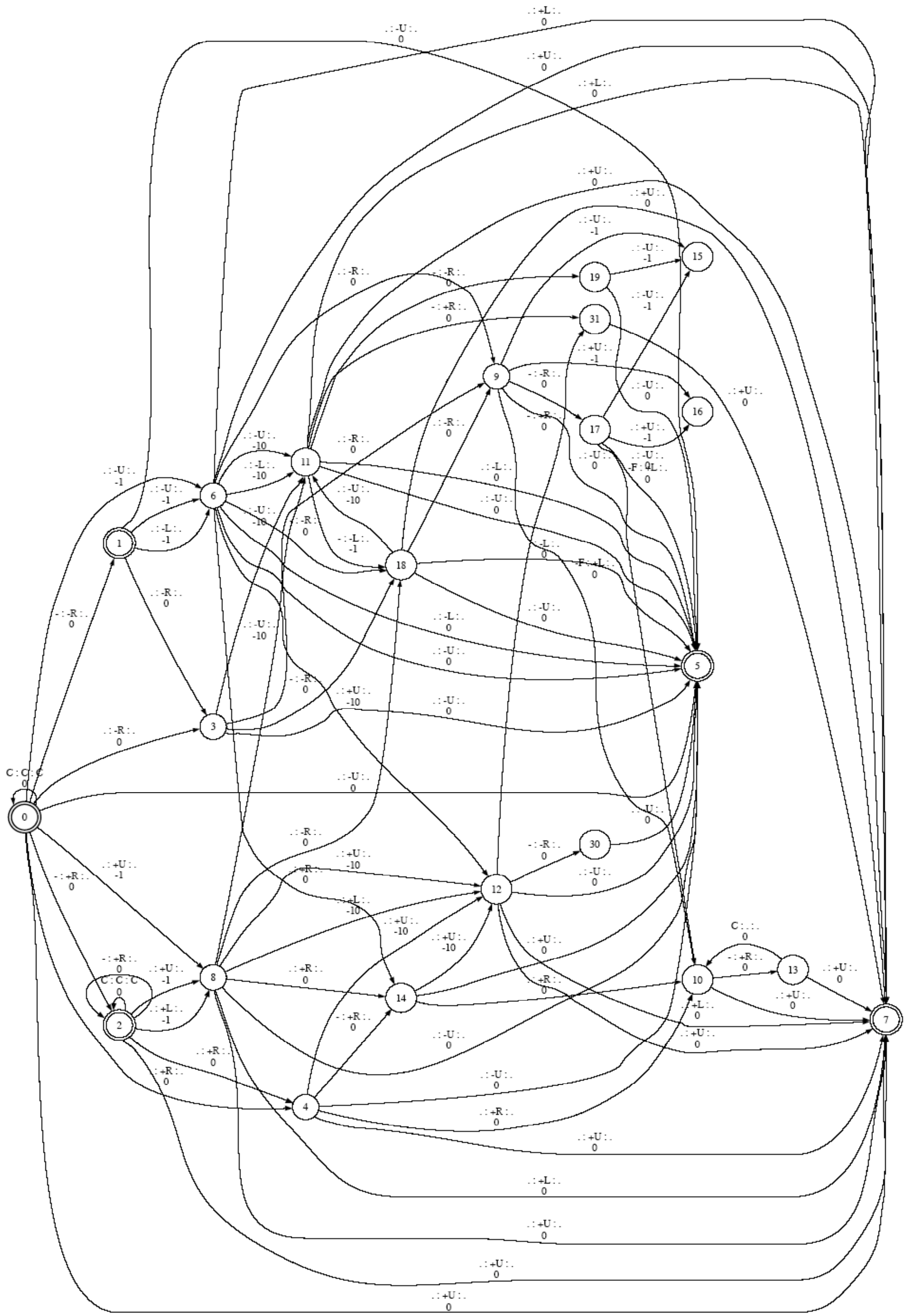
The first consonant in the candidate [C - C +: C +R C +U : C + C +] is generated by the arc [C:C:C/0] from state 0 to state 0. The epenthetic vowel is generated by the arc [-:+R:./-1] from state 0 to state 2. The second consonant is generated by the arc [C:C:C/0] from state 2 to state 2. The final vowel is generated by the arc [.:+U:./0] from state 2 to state 10. Because the epenthetic vowel undergoes leftward spreading, the epenthetic vowel incurs a violation of SPREAD-R.

5.3.2.10 SPREAD-L

One might assume that SPREAD-L should look exactly like SPREAD-R except that the projections are reversed such that being projected by an R satisfies SPREAD-R but not SPREAD-L. However, this simple reversal is not possible because of the restrictions on what can initiate spreading. For SPREAD-R, the final vowel is the optimal trigger for harmony, but for SPREAD-L the first vowel is the optimal trigger for harmony. For SPREAD-R, the machine looks for a vowel projected by U and then for vowels projected by R. With SPREAD-L, the machine looks for vowels projected by L and then must ensure that there is a vowel projected by U at the end of the string of L's. Another difference between SPREAD-R and SPREAD-L is that in SPREAD-R, the initial vowel cannot be projected by a vowel to the left, and therefore never incurs a violation of SPREAD-R. With SPREAD-L, it is the final vowel that cannot incur a violation of SPREAD-L because the final vowel has no vowel to the right to be projected by. Since the machines are designed to handle several vowels, it is not known a priori how many vowels are in the input. In reading the strings from right-to-left, it is unclear whether to assign a violation to SPREAD-L in case it is the final vowel. The solution to this is to create an 'escpe hatch' where the final vowel moves into a final accepting state that does not violate SPREAD-L. Because there are no transitions out of this state, it is only possible to move to this state if the final vowel of the string has been reached. This is a different strategy from SPREAD-R because the initial vowel, which always satisfies SPREAD-R, is automatically differentiated because it is the first vowel in the string.

SPREAD-L has three final states: state 0 (for forms with no underlying vowels), and two independent final states, one for words whose final vowel is [+F] (state 7) and one whose final vowel is [–F] (state 5). If the first vowel is projected by an R, then it satisfies SPREAD-L, otherwise it violates the constraint. For the first vowel, any vowel projected by an L, U or P gets 1 violation of SPREAD-L. For the second vowel, a violation of SPREAD-L gets 10 violations and for the third vowel (if there are four vowels), SPREAD-L gets 100 violations. The final vowel always gets 0 violations of SPREAD-L no matter what the projection is. This is because it is impossible for the final vowel to undergo leftwards spreading. Because the SPREAD constraint keeps track of the position of the vowel in the word (first, second, third, etc.) there is a separate node for each vowel position, in order to keep track of where the violation comes from. Violations of harmony from epenthetic vowels are assigned based on the position of the word. If an epenthetic vowel does not get its projected feature from the right, it will incur a violation of SPREAD-L depending on its position in the word. Epenthesis before the initial vowel gets 1 violation, epenthesis after the initial vowel gets 10 violations, etc.

(141) SPREAD-L Finite-State Machine



If the first vowel of the string is projected by U, P or L, 1 violation is assigned, and the machine moves to a state corresponding to the initial projection. If the first vowel is projected by –R, no violation is assigned, and the machine moves to a state (3) where if the vowel following it also is projected by –R, no violation is assigned. For a string of –R's this continues on until a –U is reached. If the –U is the final vowel in the word, then no violations are assigned. If the –U is not the final vowel, then a violation is assigned based on its position: –10 for the second vowel, –100 as the third vowel, etc. If the vowel is projected by U, or P, but the second vowel is projected by R, then no violations are assigned on the second transition, and the machine joins with the fully harmonic (left-to-right spreading) path through the machine.

Several [C:C:C] and [-:-:.] arcs generating consonants and epenthetic vowels were removed in order to make the diagram more legible. However, all relevant arcs for the case studies can be seen.

The candidate [+ –F –B : +U +L +L: + + –F] is generated by three arcs. The first vowel is generated by the arc from state 0 to state 8 [. : +U : . / -1], the second vowel is generated by the arc from state 8 to state 12 [. : +L . / -10] and the third vowel is generated by the arc [. : +L : . / 0] from state 12 to state 7. This candidate receives 11 violations of SPREAD-L, as this candidate undergoes full left-to-right spreading and therefore must receive the maximum violations for SPREAD-L. Overall the candidate [+ –F –B : +U +L +L: + + –F] has a constraint profile with no violations for MAX, DEP, CC, *B and SPREAD-R two violations for ID[F], 1 violation for REC and 11 violations for SPREAD-L.

The first consonant in the candidate [C - C +: C +R C +U : C + C +] is generated by the arc [C:C:C/0] from state 0 to state 0. The epenthetic vowel is generated by the arc [-:+R:./0] from state 0 to state 2. The second consonant is generated by the arc [C:C:C/0] from state 2 to state 2. The final vowel is generated by the arc [.:+U:./0] from state 2 to state 7. Because the epenthetic vowel undergoes leftward spreading, the epenthetic vowel incurs no violations of SPREAD-L.

5.4 Results

The finite state machines were fed into the CONTENDERS Algorithm. A set of 340 inputs was created using Excel to model all possible feature combinations for up to four vowels (+F, –F, +B, –B) without epenthesis. There were 256 combinations with 4 vowels in the input, 64 combinations with 3 vowels, 16 combinations with 2 vowels, and 4 with 1 vowel in the input. The input list with epenthesis used the vowel combinations for up to 3 vowels, and CC clusters were inserted at the left edge, right edge, and medially (when applicable).

Without epenthesis, when the results of the CONTENDERS algorithm were fed into a program for computing typologies using Elementary Ranking Conditions (ERC's) (Jason Riggle, personal communication), there was a typology containing 16 languages: 6 spread right, 6 spread left and 4 with no spreading. For the no spread cases, there is one language that allows the marked segment ([+B]), and three that do not. In the three that do not allow [+B] in the output, underlyingly /+B/ segments are treated differently. In one language, underlyingly /+B/ segments get their [–F] feature from the vowel to its left, in another language, underlyingly /+B/ segments get their [–F] feature from the vowel to its right, and in the third language, underlyingly /+B/ segments get their [–F] feature from the pronunciation level. The six spread right and spread left languages are identical except that one always spreads right and the other always spreads left. In one language, [+B, +F] segments are tolerated in the language. In the second language, [+B, +F] segments are only tolerated as a result of spreading. In the third language, blockers are transparent, and underlyingly /+B/ segments become [–F] by projecting from the pronunciation level. In the fourth language, blockers are also transparent, but underlyingly /+B/ segments get their [–F] feature by spreading. In the fifth language, blockers are opaque, and underlying /+B/ segments change to [–F] via spreading or projection from the surface form when spreading is not possible. In the sixth language, blockers are also opaque, but if spreading cannot occur in the primary direction (e.g. left-to-right) spreading occurs in the other direction (right-to-left). This is essentially a bi-directional harmony system with one direction as the default.

With epenthesis, the predicted typology contains 68 languages. There are 16 languages with no epenthesis, 16 languages with epenthesis always on the projection level and 16 languages with epenthesis at the pronunciation level. Each of these sets of 16 languages corresponds to the 16 languages with no epenthesis above. In addition, there are 10 languages with epenthesis at the projection level if the epenthetic vowel can get its features from the vowel to its left, and epenthesis at the pronunciation level otherwise. These 10 languages are 4 no-spread languages and 6 spread-right languages, from above. There are 10 languages with epenthesis at the projection level if the epenthetic vowel can get its features from the vowel to its right, and epenthesis at the pronunciation level otherwise. These 10 languages include 4 no-spread languages and 6 spread-left languages, from above. Altogether, there are 68 languages (16 x 3 + 10 x 2). An important result of these computations is that epenthesis is never blocked by a failure to participate in harmony, which is the pathological prediction that must be avoided in order ti create a myopic theory of vowel harmony. The list of all 68 languages and their rankings are given in the appendix.

While I will not present real-world examples of all 68 languages, there are example languages that fit all of the general patterns. For example, there are languages with transparent vowels, opaque vowels, vowels that undergo harmony, etc. The table in (142) below describes nine patterns that can be gleaned from the 68 languages above, with real-world examples of each.

(142) Patterns of Harmony Language with Attested Examples

Pattern	**Example Languages**
1. No Non-Participating Vowels	Kalenjin, Degema, Diola Fogni (ATR) Turkish ([BACK])
2. Transparent Vowels	Hungarian, Finnish (high vowel transparent to back harmony) Pasiego ([e] transparent to [ATR] harmony)
3. Opaque Vowels	Mongolian ([ROUND]), Tangale (ATR), Turkish (low vowels transparent to round harmony)
4. Bi-Directional Harmony	Lango (ATR)
5. Marked Vowels Tolerated as Result of Vowel Harmony	Pasiego ([–ATR] vowels)
6. Epenthetic Vowels Transparent to Harmony	Karchevan, Agulus, (back harmony) Karimojong (ATR harmony)
7. Epenthetic Vowels Participate in Harmony	Turkish, Yawelmani, (back/round harmony) Yoruba (ATR), Chuckchee (ATR)
8. Harmony in Epenthetic Vowels Directional	Levantine Arabic (height), Mohawk, Sesotho (vowel copy from right)
9. Vowel Harmony only in Epenthetic Vowels	Ponapean (round), Barra Gaelic (vowel copy), Marash (vowel copy), Winnegbeo (vowel copy)

Type 1 languages are harmony languages in which all possible vowels participate in harmony. These languages usually have symmetric inventories such that all vowels have harmonic counterparts. For example, Nandi-Kipsigis Kalenjin, a Southern Nilotic language, (Hall et al., 1973; Lodge, 1995; Martin, 1985) has a dominant-recessive [ATR] harmony system, where [+ATR] is dominant.

(143) Vowel inventory ([–ATR] vowels are the rightmost member of each pair):

i, ɪ		u, ʊ
e, ɛ		o, ɔ
	æ, a	

Because of the symmetrical inventory, the presence of a [+ATR] vowel in the input will cause all underlyingly [–ATR] vowels to assimilate to the [+ATR] vowel in the output, as illustrated in (144). Roots are marked with a √ (Bakovic 2000).

(144) Vowel harmony in Nandi-Kipsigis Kalenjin:

(a)	/√pa:n-a:n/	[pa:na:n]	'that walk'
	/√tjæ:n -a:n/	[tjæ:næ:n]	'that beast'
(b)	/√ke:r-ʊn/	[ke:r-un]	'see it from here'
	/√kʊt-ʊn/	[kʊt-ʊn]	'blow it here'
(c)	/√sal-ɔ/	[sal-ɔ]	'painting'
	/√sal-u:t/	[sæl-u:t]	'a paint job'
(d)	/ka-a-√kʊ:t-ʊn /	[ka:ɣʊ:ntʊn]	'I blew it'
	/ka-a-√kʊ:t-e/	[kæ:ɣu:te]	'I was blowing'

In (a.) and (b.), the [ATR] specification of the affix varies by the [ATR] value of the root. In (c.) and (d.), the [ATR] value of the root may change in the presence of some affixes, showing the dominant-recessive nature of Kalenjin vowel harmony.

Type 2 languages have transparent vowels. This occurs when the inventory of sounds does not include a contrast for all vowels. For example, the Pasiego dialect of Montañes (spoken in the province of Santander in north-central Spain) exhibits a morphologically controlled [ATR] harmony in which the masculine singular suffix ([-ʊ]) forces all vowels in the lexical item to be [–ATR], except that the vowel [e] is transparent to harmony. This is illustrated in (145).

(145) [ATR] harmony in Pasiego dialect of Montañes (McCarthy, 1984)

	[+ATR]	[–ATR]	‘gloss’	Semantic Distinction (count nouns plural/ count
(a)	[pustíjæ]	[pʊstɪ́jʊ]	‘scab’	dim./singular
(b)	[komfesonǽrjus]	[kɔmf**e**sɔnárjʊ]	‘confessional’	plural/singular
(c)	[pitrína]	[pɪtrɪ́nʊ]	‘waistband’	dim./singular

In (145) (b) the vowel [e] does not undergo harmony, but all other vowels spread through the transparent vowel. In type 5 languages, a marked feature value is present only as the result of harmony. Pasiego is also an example of a type 5 language because the [–ATR] vowels only appear as a result of harmony. While [e] is transparent to vowel harmony, all other [–ATR] vowels emerge as a result of spreading.

In type 3 languages, non-participating vowels block harmony, as in Turkish, described in Chapter 4. These data are repeated here. Turkish displays both round and back harmony, with several conditioning factors. First, only high vowels undergo round harmony; non-high round vowels are licensed only in stems, and only suffixes containing high vowels are affected by round harmony (Bakovic, 2000; Clements & Sezer, 1982; J. Cole & Kisseberth, 1994). Second, non-high vowels are opaque to round harmony, but all vowels undergo back harmony (Clements & Sezer, 1982; Erdal, 2004; Kirchner, 1993; Polgardi, 1999). Third, stems may be disharmonic with respect to both round and back vowel harmony. The (less restrictive) word initial vowel inventory is given in (100) below.

(146) Turkish (Word-Initial) Vowel Inventory (Clements & Sezer, 1982; Polgardi, 1999)

	Front		Back	
	Non-round	Round	Non-round	Round
High	i	y	ɨ	u
Non-High	e	ø	a	o

Harmonic suffixes alternate in both [BACK] as well as [ROUND] features. This is illustrated in (101) below, in which the high suffix vowel becomes [ROUND] if the stem vowel is [ROUND], and all vowels agree in [BACK].

(147) Vowel Harmony in Turkish (Clements & Sezer, 1982; Polgardi, 1999)

	Nom Sg	Gen Sg	Nom Pl	Gen Pl	Gloss
(a)	[ip]	[ip-in]	[ip-ler]	[ip-ler-in]	'rope'
(b)	[kɨz]	[kɨz-ɨn]	[kɨz-lar]	[kɨz-lar-ɨn]	'girl'
(c)	[jyz]	[jyz-yn]	[jyz-ler]	[jyz-ler-in]	'face'
(d)	[pul]	[pul-un]	[pul-lar]	[pul-lar-ɨn]	'stamp'
(e)	[el]	[el-in]	[el-ler]	[el-ler-in]	'hand'
(f)	[sap]	[sap-ɨn]	[sap-lar]	[sap-lar-ɨn]	'stalk'
(g)	[køj]	[køj-yn]	[køj-ler]	[køj-ler-in]	'village'
(h)	[son]	[son-un]	[son-lar]	[son-lar-ɨn]	'end'

The genitive singular suffix /-in/ has four allomorphs, depending on the [ROUND] and [BACK] specification of the final root vowel. The nominative plural suffix /-ler/ has only two allomorphs, front ([ler]) and back ([lar]), because, although round non-high vowels can appear in stems, non-high vowels do not participate in round harmony and suffixal vowels are always non-round.

Turkish is also a type 7 language, in which epenthetic vowels participate in harmony. Because epenthetic vowels are always high, epenthetic vowels always participate in both back and round harmony (Clements & Sezer, 1982; Kirchner, 1993). This is illustrated in (102) below.

(148) Epenthetic Vowels Participate in Vowel Harmony (Kirchner, 1993)

a. /hükm/ → hük**ü**m 'judgment'
b. /kojn/ →koj**u**n 'bosom'
c. /metn/ →met**i**n 'text'
d. /sabr/ →sab**ɨ**r 'patience'

Turkish is an example where epenthetic vowels participate in the harmony process of the language.

In Type 4 languages, vowel harmony is bi-directional such that if harmony cannot apply in the default direction, harmony applies in the opposite direction. This type of harmony can be found in Lango, a Nilotic language of Luganda (Archangeli & Pulleyblank, 1994; Kaplan, 2007, 2008; Okello, 1975; Poser, 1982; Smolensky, 2006; Woock & Nooonan, 1979). Lango has an ATR harmony system that primarily proceeds from left-to-right. However, when the target for harmony is a [+High, +ATR] vowel, the direction of spreading may reverse.

In Type 6 languages, epenthetic vowels are transparent to harmony, as described in Chapter 4 above for Agulus. These data are repeated here. Many Armenian dialects undergo both backness vowel harmony and epenthesis. In this section, I describe the data from Agulis, which has backness vowel harmony, but epenthetic vowels do not participate in harmony (Vaux 1998). In (97) the suffix vowel assimilates to the backness feature of the stem.

(149) Regular Back Vowel Harmony (Vaux 1998)

a.	/ton-ar/	[tónar]	'houses'
b.	/dejz-ar/	[djézær]	'heaps'
c.	/hat^{h}s-er-am/	[hat^{h}séræm][11]	'bread-pl-intr.'

[11] Note that low vowels do not trigger harmony in Agulus.

In (98), the epenthetic vowel is disharmonic with the stem vowel. Note that the /a/ in (a.) and (b.) change to [o] and [u] based on independent processes affecting final stressed vowels (and stressed vowels preceding nasals) (epenthetic vowels are in **bold**).

(150) Agulus Harmony and Epenthesis (Vaux 1998)

a.	/hrat/	[h**ə**rót]	'advice'
b.	/nʃan/	[n**ə**ʃún]	'sign
c.	/sur-ats/	[surat**ə**s]	'tomb'

Clusters are broken up with the vowel [ə], but [ə] does not participate in harmony in any way ([ə] does not trigger or undergo harmony). Epenthetic vowels are transparent to harmony.

In type 8 languages, epenthetic vowels are directional. This was found in Sesotho, discussed in Chapter 4 above. In this language, epenthetic vowels undergo vowel copy, only when a vowel is present to the left, as in /blik/ ⇒ [balik] versus /hebru/ ⇒ [heberu] (Rose & Demuth, 2006).

In type 9 languages, there is no harmony in the language except for epenthetic vowels. This occurs for Winnebego, (Miner, 1979; van Oostendorp, 2007), in which there is no harmony, but epenthetic vowels are subject to epenthetic vowel copy.

(151) Epenthetic Vowels in Winnebego (van Oostendorp, 2007)
(a) x<u>o</u>rojike 'hollow'
(b) hojis<u>a</u>na 'recently'
(c) hirup<u>i</u>ni 'twist'

It is therefore not necessary for a language to have vowel harmony to make its epenthetic vowels subject to harmony. This type of language is predicted by Turbid Spreading.

The factorial typology produces an attested set of languages. While more work is needed in order to produce the complete typology of vowel harmony with all its idiosyncrasies, the typology it predicts strongly suggests that the present proposal for a theory of vowel harmony is on the correct track.

5.5 Conclusion

This chapter has provided a formal approach to factorial typologies for complex theories of representation in Optimality Theory. I have illustrated that the representations in Turbid Spreading can be generated and evaluated by finite-state machines that may be used to compute a factorial typology of languages. The results produced 68 languages, whose interactions are attested in natural languages. Specifically, I have argued that the theory of Turbid Spreading avoids known harmony pathologies and avoids predicting pathologies that had not been considered previously.

This concludes the theoretical portion of the dissertation. The next chapters present experimental work that provides insights into the representations used in vowel harmony. While some of the experimental work addresses questions that are more general to phonological theory (i.e., feature-based representations), other work is directly related to the myopia question raised in this section, including testing for a majority rules bias and a directionality bias.

Appendix I: Factorial Typology of Vowel Harmony and Epenthesis

Language	Ranking	Description
1	SPREAD-L, *B, DEP >> SPREAD-R, REC, *CC >> ID	No epenthesis Spread-L [+B] Transparent
2	REC, *B, DEP >> SPREAD-L *CC >> SPREAD-R >> ID	No epenthesis Spread-L [+B] Opaque, spread-right
3	REC, *B, DEP >> SPREAD-L *CC >> ID >> SPREAD-R	No epenthesis Spread-L [+B] Opaque, [+B] projects [+B]
4	SPREAD-L, REC, DEP >> SPREAD-R, *B, *CC >> ID	No epenthesis Spread-L [+B] tolerated from spreading
5	REC,*B, DEP >> SPREAD-R, *CC >> ID >> SPREAD-L	No epenthesis Spread-R [+B] Opaque, projects [+B]
6	REC, *B, DEP >> SPREAD-R *CC >> SPREAD-L >> ID	No epenthesis Spread-R [+B] Opaque, Spread-L
7	SPREAD-R, REC, DEP >> SPREAD-L, *B, *CC >> ID	No epenthesis Spread-R [+B] tolerated from spreading
8	SPREAD-R, *B, DEP >> SPREAD-L, REC, *CC >> ID	No epenthesis Spread-R [+B] Transparent
9	REC, *B, DEP >> ID, *CC >> SPREAD-R >> SPREAD-L	No epenthesis No Spread Covert Right
10	REC, *B, DEP >> ID, *CC >> SPREAD-L >> SPREAD-R	No epenthesis No Spread Covert Left
11	SPREAD-L, REC, DEP >> SPREAD-R, ID, *CC >> *B	No epenthesis Spread-L [+B] tolerated
12	SPREAD-R, REC, DEP >> SPREAD-L, ID, *CC >> *B	No epenthesis Spread-R [+B] tolerated
13	REC, ID, DEP >> SPREAD-R SPREAD-L, *B, *CC	No epenthesis No Spread [+B] tolerated
14	SPREAD-L, *B, DEP >> SPREAD-R, ID, *CC >> REC	No epenthesis Spread-L [+B] transparent
15	SPREAD-R, *B, DEP >>	No epenthesis

	SPREAD-L, ID *CC >> REC	Spread-R [+B] transparent
16	ID, *B, DEP >> SPREAD-R, SPREAD-L, REC, *CC	No epenthesis No Spread [+B] projects [+B]
17	SPREAD-L, REC, *CC >> ID, DEP >> SPREAD-R, *B	Spread-L to epenthetic vowel, otherwise no spread Spread-L [+B] tolerated
18	REC, ID, *CC >> SPREAD-L *B >> DEP >> SPREAD-R	Spread-L to epenthetic vowel, otherwise no spread No Spread [+B] tolerated
19	SPREAD-L, *B, *CC >> REC, DEP >> SPREAD-R, ID	Spread-L to epenthetic vowel, otherwise no spread Spread-L [+B] transparent
20	REC, *B ,*CC >> SPREAD-L >> ID >> DEP >> SPREAD-R	Spread-L to epenthetic vowel, otherwise no spread Spread-L [+B] opaque, projects [+B]
21	REC, *B, *CC >> SPREAD-L >> DEP >> SPREAD-R, ID	Spread-L to epenthetic vowel, otherwise no spread Spread-L [+B] opaque, spread-right
22	SPREAD-L, REC, *CC >> *B, DEP >> SPREAD-R, ID	Spread-L to epenthetic vowel, otherwise no spread Spread-L [+B] tolerated from spreading
23	REC, *B, *CC >> ID >> SPREAD-L >> DEP >> SPREAD-R	Spread-L to epenthetic vowel, otherwise no spread No spread [+B] projects from pronunciation
24	SPREAD-L, *B, *CC >> ID DEP >> SPREAD-R, REC	Spread-L to epenthetic vowel, otherwise no spread Spread-L [+B] transparent
25	ID, *B, *CC >> SPREAD-L REC >> DEP >> SPREAD-R	Spread-L to epenthetic vowel, otherwise no spread No Spread [+B] projects [+B]
26	SPREAD-R, REC, *CC >> SPREAD-L, ID >> *B, DEP	No Spread to Epenthetic Vowel Spread-R [+B] tolerated
27	SPREAD-L, REC, *CC >> SPREAD-R, ID >> *B, DEP	No Spread to Epenthetic Vowel Spread-L

		[+B] tolerated
28	REC, ID, *CC >> SPREAD-R SPREAD-L, *B >> DEP	No Spread to Epenthetic Vowel No Spread [+B] tolerated
29	SPREAD-R, *B, *CC >> SPREAD-L, REC >> ID, DEP	No Spread to Epenthetic Vowel Spread-R [+B] transparent
30	REC, *B, *CC >> SPREAD-R >> SPREAD-L >> ID, DEP	No Spread to Epenthetic Vowel Spread-R [+B] opaque, spread-left
31	REC, *B, *CC >> SPREAD-R >> ID >> SPREAD-L >> DEP	No Spread to Epenthetic Vowel Spread-R [+B] opaque, project from pronunciation
32	SPREAD-R, REC, *CC >> SPREAD-L, *B >> ID, DEP	No Spread to Epenthetic Vowel Spread-R [+B] from spreading
33	SPREAD-L, *B, *CC >> SPREAD-R, REC >> ID, DEP	No Spread to Epenthetic Vowel Spread-L [+B] transparent
34	REC, *B, *CC >> SPREAD-L >> ID >> SPREAD-R >> DEP	No Spread to Epenthetic Vowel Spread-L [+B] opaque, project from pronunciation
35	REC, *B, *CC >> SPREAD-L >> SPREAD-R >> ID, DEP	No Spread to Epenthetic Vowel Spread-L [+B] opaque, spread right
36	SPREAD-L, REC, *CC >> SPREAD-R, *B >> ID, DEP	No Spread to Epenthetic Vowel Spread-L [+B] from spreading
37	REC, *B, *CC >> ID >> SPREAD-L >> SPREAD-R >> DEP	No Spread to Epenthetic Vowel No Spread Covert spread Left
38	REC, *B, *CC >> ID >> SPREAD-R >> SPREAD-L >> DEP	No Spread to Epenthetic Vowel No Spread Covert Spread Right
39	SPREAD-R, *B, *CC >> SPREAD-L, ID >> REC, DEP	No Spread to Epenthetic Vowel Spread-R [+B] Transparent
40	SPREAD-L, *B, *CC >> SPREAD-R, ID >> REC, DEP	No Spread to Epenthetic Vowel Spread-L [+B] opaque, spread right
41	ID, *B, *CC >> SPREAD-R, SPREAD-L, REC >> DEP	No Spread to Epenthetic Vowel No Spread [+B] projects [+B]
42	*B, *CC >> DEP >> SPREAD-L >> SPREAD-R, ID >> REC	Spread-L to epenthetic vowel, otherwise right Spread-L [+B] opaque, spread-right

43	ID, *B, *CC >> REC, DEP >> SPREAD-L >> SPREAD-R	Spread-L to epenthetic vowel, otherwise right No Spread [+B] projects [+B]
44	ID, *B, *CC >> REC, DEP >> SPREAD-R >> SPREAD-L	Spread-R to epenthetic vowel, otherwise right No Spread [+B] projects [+B]
45	*B, *CC >> DEP >> SPREAD-R >> SPREAD-L, ID >> REC	Spread-R to epenthetic vowel, otherwise right Spread-R [+B] transparent
46	REC, *CC >> DEP >> SPREAD-L >> SPREAD-R, ID >> *B	Spread-L to epenthetic vowel, otherwise right Spread-L [+B] tolerated
47	REC, ID, *CC >> *B DEP >> SPREAD-L >> SPREAD-R	Spread-L to epenthetic vowel, otherwise right No Spread [+B] tolerated
48	REC, ID, *CC >> *B DEP >> SPREAD-R >> SPREAD-L	Spread-R to epenthetic vowel, otherwise left No Spread [+B] tolerated
49	REC, *CC >> DEP >> SPREAD-R >> SPREAD-L, ID >> *B	Spread-R to epenthetic vowel, otherwise left Spread-R [+B] tolerated
50	REC, *B, *CC >> DEP >> SPREAD-L >> SPREAD-R >> ID	Spread-L to epenthetic vowel, otherwise right Spread-L [+B] opaque, spread-right
51	REC, *B, *CC >> DEP >> SPREAD-L >> ID >> SPREAD-R	Spread-L to epenthetic vowel, otherwise right Spread-L [+B] opaque, projects from pronunciation
52	REC, *CC >> DEP >> SPREAD-L >> SPREAD-R, *B >> ID	Spread-L to epenthetic vowel, otherwise right Spread-L [+B] from spreading
53	*B, *CC >> DEP >> SPREAD-L >> SPREAD-R REC >> ID	Spread-L to epenthetic vowel, otherwise right Spread-L [+B] opaque, spread-right
54	REC, *B, *CC >> ID, DEP >> SPREAD-L >> SPREAD-R	Spread-L to epenthetic vowel, otherwise right No Spread [+B] projects from pronunciation
55	REC, *B, *CC >> ID, DEP >> SPREAD-R >> SPREAD-L	Spread-R to epenthetic vowel, otherwise left No Spread [+B] projects from pronunciation
56	*B, *CC >> DEP >> SPREAD-R >> SPREAD-L REC >> ID	Spread-R to epenthetic vowel, otherwise left Spread-R [+B] transparent
57	REC, *B, *CC >> DEP >> SPREAD-R >> ID >> SPREAD-L	Spread-R to epenthetic vowel, otherwise left Spread-R [+B] projects from pronunciation
58	REC, *B, *CC >> DEP >>	Spread-R to epenthetic vowel, otherwise left

	SPREAD-R >> SPREAD-L >> ID	Spread-R [+B] opaque, spread-left
59	REC, *CC >> DEP >> SPREAD-R >> SPREAD-L, *B >> ID	Spread-R to epenthetic vowel, otherwise left Spread-R [+B] tolerated if spreading
60	ID, *B, *CC >> SPREAD-R REC >> DEP >> SPREAD-L	Spread-R to epenthetic vowel otherwise no spread No Spread [+B] projects [+B]
61	SPREAD-R, *B, *CC >> ID DEP >> SPREAD-L, REC	Spread-R to epenthetic vowel otherwise no spread Spread-R [+B] transparent
62	REC, ID, *CC >> SPREAD-R, *B >> DEP >> SPREAD-L	Spread-R to epenthetic vowel otherwise no spread No Spread [+B] tolerated
63	SPREAD-R, REC, *CC >> ID, DEP >> SPREAD-L, *B	Spread-R to epenthetic vowel otherwise no spread Spread-R [+B] tolerated
64	REC, *B, *CC >> ID >> SPREAD-R >> DEP >> SPREAD-L	Spread-R to epenthetic vowel otherwise no spread No Spread Covert spread-right
65	SPREAD-R, *B, *CC >> REC, DEP >> SPREAD-L, ID	Spread-R to epenthetic vowel otherwise no spread Spread-R [+B] transparent
66	REC, *B, *CC >> SPREAD-R >> ID, DEP >> SPREAD-L	Spread-R to epenthetic vowel otherwise no spread Spread-R [+B] opaque, projects [+B]
67	REC, *B, *CC >> SPREAD-R >> DEP >> SPREAD-L >> ID	Spread-R to epenthetic vowel otherwise no spread Spread-R [+B] opaque, spread left
68	SPREAD-R, REC, *CC >> *B, DEP >> SPREAD-L, ID	Spread-R to epenthetic vowel otherwise no spread Spread-R [+B] tolerated if spread

Chapter 6: Overview of Experimental Work

This chapter is designed to serve as the bridge between the experimental and theoretical work presented in this dissertation. All of the theoretical work and all of experimental work focus on vowel harmony, but there is a hope that an even deeper connection can be made between these two approaches. Mainly, I propose that the typology of vowel harmony languages explained in the previous chapters arises primarily out of learning biases. That is, it is no accident that vowel harmony languages are restricted such that the vast majority of harmony processes are local and iterative, with a select set of interactions between vowel harmony and other phonological processes (such as epenthesis). My thesis is that the typology of phonological processes that are found in the world's languages arise out of substantive biases.

6.1 Understanding Linguistic Typologies

The goals of generative linguistics are to understand the nature of cross-linguistic typology, to form a theory of grammar that captures all possible languages but will not generate unattested languages, and to understand the nature of the mind that is compatible with the way that language is structured. In trying to understand why some languages are unattested or rare, there is no way to distinguish between an accidental gap and a banned system. It is also speculative what causes some patterns to be rare compared to others that are found in a wide variety of languages. If such patterns are governed by phonetic naturalness, it may be the case that natural patterns are easier to learn than unnatural patterns. However, there may also be grammatical factors that govern learning, such as the nature of the features involved in the phonological process. Finally, the patterns that are easiest to learn may be regulated by non-linguistic facros such as working memory and attention. The experiments presented here support the hypothesis that language typology is shaped by learning biases. However, these experiments do not explicitly test for the origins of these biases, and all claims about the origin of learning biases are based on independently attested phonetic, phonological and cognitive principles.

6.2 Substantively Biased Learning

While the experiments presented here do not test for the precise nature of learning biases, they do support a substantively biased theory of learning biases that is shaped by an interaction of factors: phonetic, phonological and cognitive (Wilson, 2006). The theory of substantively biased learning states that learning novel phonological patterns is based on knowledge of the grammatical structure of phonological processes as well as on phonetic factors such as articulation and perception. Constraints on the typology of vowel harmony raise the question of whether the substance that forms these constraints is psychologically real. Following Wilson (2006), substance is defined as “the system of categories that figure into the mental representation of linguistic knowledge” (945). This includes abstract representations that are used to describe phonological processes such as distinctive features, natural classes, as well as the basic vocabulary for describing phonological units: the syllable, prosodic word, stress, consonant, and vowel. Substance also refers to the psychological instantiation of theoretical notions that may be specific to a particular phonological framework, such as constraints in Optimality Theory (Prince and Smolensky 1993/2004).

Substantive biases guide learners towards phonological processes that conform to the substantive knowledge of the learner, acting as a prior on learning; the learner forms hypotheses about the training data based on knowledge of what phonological processes should look like. For example, if language learners have knowledge of features and natural classes, they will be biased to posit rules that make use of these features and natural classes. Further, if learners have knowledge about what makes a proper grammatical process, then they should be biased towards learning natural phonological processes.

While the theory of the substantive nature of phonology stems from precise, formal research in phonetics and theoretical phonology, there is no comprehensive list of what qualifies as substantive knowledge in phonology. However, there are several principles that apply to a substantive theory of phonology (Chomsky, 1965; Chomsky & Halle, 1968; Flemming, 1995; Hayes, 1999; Wilson, 2001, 2006). The first of these principles is that of phonological markedness (Hayes & Steriade, 2004; Jakobson, 1968): phonological processes should strive to make sounds as perceptible as possible without sacrificing lexical distinctions. Second, phonological processes must be as structurally simple as possible. For example, there is a bias for phonological processes to apply to a single natural class, rather than a disjunctive group of unrelated segments (Moreton, in prep). Third, learners are equipped with phonetic and phonological knowledge of the segments in their language (Hayes & Londe, 2006; Hayes & Wilson, to appear), and are therefore able to generalize over features. For example, learners know that the vowel [u] shares the feature [Back] with the vowel [a], but the feature [High] with the vowel [i]. All of these basic principles can be used to deduce whether a particular process (e.g., vowel harmony) can apply to a particular vowel. A morphophonological alternation in which some instances of a suffix surface with the vowel [i] and other instances surface with the vowel [u] involves both a change in the feature [Back] as well as [Round]. Learners are biased to include only vowels that alternate in both [Back] and [Round] in their harmony rule. Because mid vowels [e] and [o] differ in both features [Back] and [Round], learners should have no problem extending the harmony rule to these vowels. However, low vowels [a] and [æ] only differ in the feature [Back], predicting no extension to low vowels.

According to the substantively biased learning hypothesis, the two most likely sources for learning biases are innate knowledge of linguistic systems and of knowledge of phonetic and phonological principles that emerges with experience with the native language. Innate knowledge may include the set of universal phonological features and how these features relate to one another (e.g., feature geometry (Clements, 1985) or feet structure in stress systems (Hayes, 1995)) or a universal, initial ranking of phonological constraints (Tesar & Smolensky, 1998). Perceptual and articulatory experience with one's native language may create general preferences for grammatical structure, many of which will mirror those restrictions found cross-linguistically (Hayes, 1999). The hypothesis is that a combination of innate knowledge and experience with sounds of the native language should give rise to knowledge of general principles of acoustics, perception and phonological structure. This knowledge produces a strategy for phonological learning that makes use of a wide range of knowledge, from general principles of language structure to specific phonetic facts pertaining to the specific novel language data.

6.3 The Artificial Grammar Learning Paradigm

Understanding typology in terms of learning is difficult using traditional methods for linguistic inquiry for several reasons. First, it is impossible to test whether or how children learn unattested patterns if children never have access to these unattested patterns. Even comparing the learning of rare versus common phonological patterns is problematic as there are many competing factors such that no two language learning situations are the same. Coupled with the noisy data of individual differences, understanding the nature of learning biases for phonological patterns is particularly challenging in the natural setting. One way of testing learning biases, not only for attested languages, but also for unattested languages is to use an artificial setting. In an artificial experimental session, it becomes possible to manipulate the typological factors of the language being learned and control for language experience.

The experimental work presented in this dissertation uses a variant of the artificial grammar learning paradigm (Reber, 1967). In this paradigm, adult participants are presented with auditory stimuli that conforms to a single grammatical alternation. The pattern is presented through multiple exemplars repeated several times. Following this brief exposure, the participants are tested on their knowledge of the grammatical pattern using a forced choice grammaticality test; one item conforms to the phonological pattern and is grammatical, the other does not conform to the grammatical pattern and is ungrammatical. In the experiements in this study, test are divided into three conditions: items explicitly heard at training, novel items that are similar to those heard at training, and items that differ from the items heard at training, either by containing novel segments or novel morphophonological alternations. Familiar items are presented in order to assess memory for the items that the learner was trained on. Novel transfer items assess the participants' ability to extend the pattern to new items, and ensure that participants did not simply learn a memorized list of items (Redington & Chater, 1996). The second transfer condition, referred to as the 'hold-out' condition, is an innovation of the poverty of the stimulus paradigm (Wilson, 2006) which tests for generalization beyond the superficial properties of the training set. By testing how participants are able to generalize to different types of novel stimuli, we can get a better picture of the types of representations that are used in phonological rule learning, and perhaps a better picture of how vowel harmony systems work in general.

Because experiments using artificial grammars are often aimed at answering questions about language learning and the language faculty, many experiments are conducted with young children. The range of experiments that can be performed with young children is quite limited, however, because of the difficulties in getting an infant to learn a grammar in a short amount of time, and with identifying a reliable measure of the learning pattern. Because of these attentional and cognitive constraints, the vast majority of infant research trains young learners on simple patterns, such as a basic phonotactic constraint or a phonemic contrast (Best & McRoberts, 2003; Gerken, 2002; Jaeger, 1986; Maye, Werker, & Gerken, 2002; Onishi, Chambers, & Fisher, 2002; White, Peperkamp, Kirk, & Morgan, 2008).

The experimental data presented in this dissertation tests adult learning of novel phonological patterns (all native English speakers). I therefore assume that the learning biases that are present in our adult learners are in some way present in learners of natural language. While there may be effects of English that would otherwise not be present in infant English speakers, I assume that these effects will be minimal given that vowel harmony is not present in the English language, and with the abundance of reduced vowels, unlikely to be present in the ambient statistics of the language. However, to ensure that learners make use of general learning strategies rather than on biases based on their knowledge of English, all experiments include a control condition.

6.4 Evidence for Substantively Biased Learning

There is good reason to believe that substantive biases are at work in language learning, both in terms of phonetic grounding as well as grammatical grounding. For example, several studies suggest that phonetically natural phonological rules (or processes) are more learnable compared to their phonetically unnatural counterparts (Carpenter, 2005; Schane, Tranel, & Lane, 1974; Tessier, submitted; Wilson, 2003b). Further studies demonstrate that learning of arbitrary patterns is more difficult than learning grammatically simple patterns (Pycha, Nowak, Shin, & Shosted, 2003). In the next section, I will discuss these results, and make an attempt to interpret their meaning in spite of the fact that many experiments looking for an effect of phonetic or grammatical naturalness effects often produce a null result.

6.4.1 Evidence for Phonetically-Based Biases

Several studies have tested for an effect of phonetic naturalness in learning. In the vast majority of experiments in these studies, a phonetically unnatural rule is pitted against a phonetically natural rule. The experimenter compares the learning rates of the natural rule to the unnatural rule and an effect of naturalness is found if learning is greater for the natural rule. One of the earliest of studies testing the effects of phonetic naturalness taught English speakers one of two syllable repair rules (Schane et al., 1974). The natural rule deleted consonants before vowels (creating unmarked CV syllables), while the unnatural rule deleted consonants before vowels (creating marked onsetless V) syllables. Shane et al. demonstrated that adult speakers could learn both rules, but the unnatural rule required considerably more training than the natural rule. In addition, learners of the unnatural rule made many more mistakes than learners of the natural rule.

Wilson (2003b) used an artificial language learning task to test whether adults are biased towards learning assimilation patterns that are natural. In Wilson's experiment, participants were exposed to pseudo-morphologically complex words, all ending in either [-la] or [-na]. Whether the word ended in [-la] or [-na] depended on the quality of the final consonant in the pseudo-stem. In the natural condition, the alternation was conditioned by nasal harmony; if the final consonant was a nasal, [-na] appeared, otherwise [-la] was the final syllable. In the unnatural condition, [-na] appeared if the final consonant was dorsal.

Knowledge of the phonological rules was tested using a memory task. Participants were given suffixed forms and asked whether they had heard the words before in the training task. There were four types of test items. The first was words that were heard in the training. The second was words in which the stem was heard in training, but an incorrect suffix was attached. The third and fourth types were new stems, half of which had grammatical suffixes, and the other half had ungrammatical suffixes. If participants learned the phonological rule, they should both be able to correctly identify items heard in training with the correct stem, and they should be more likely to incorrectly say "yes" to new items with a grammatical suffix. If learners are biased towards the natural rule, participants in the natural condition should misremember new grammatical items more often than participants in the unnatural condition. Participants in both groups had equivalent performances on the task. That is, they both were just as able to remember the words heard at training and the suffixes that went with it. However, the errors for participants in the natural group were biased towards misremembering new grammatical stems, with the errors for participants in the unnatural condition showed no pattern. This suggests that learners are more likely to make broader generalizations if the phonological rule they learn is natural as opposed to unnatural.

Pater and Tessier (2003) also used an artificial language to test the effects of naturalness on learning phonological alternations. In their experiment, adult native English speakers were exposed to one of two artificial languages. Both artificial languages gave alternations between singular and plural, with /-so/ as the plural suffix. In Language 1, consonant ([t]) epenthesis was used to repair sub-minimal words (less tha two syllables). The minimal word in this artificial language was a single syllable with a heavy syllable. For example, the singular form /blɪ/ was repaired to be [blɪt]. In Language 2, epenthesis was performed in an arbitrary manner, for single-syllable words ending in a front vowel. Exposure to the language involved forming a semantic association between the singular and plural forms by simultaneously presenting a visual stimulus with each auditory presentation. After exposure to the language, participants were tested using a forced choice task. They were given a pair of singular forms, each identical in all respects except one ended in a final [t], while the other did not. Results showed that those exposed to Language 1 performed better than those in Language 2, suggesting that the phonologically natural rules may be easier to learn. The authors note a potential confound in their study. In English, there are no words ending in a lax vowel so *[blɪ] is actually an ill-formed in English, as well as Language 1. Therefore, participants exposed to Language 1 may have performed better than those who were exposed to Language 2 because the incorrect choice in Language 1 was ungrammatical in English, while this was not the case for Language 2.

Wilson (2006) made use of the poverty of the stimulus paradigm to test for phonetic naturalness effects in learning a velar palatalization pattern. Cross linguistically, velar palatalization affects different segments asymmetrically, forming a universal implicational hierarchy. Velar palatalization affects velar stops before front vowels. The implicational hierarchy is that palatalization is more likely to occur before high vowels, and least likely to occur before low vowels. If palatalization occurs before a low vowel, it will also occur before mid and high vowels. There is also an implicational relationship for voicing; voiceless velars are more likely to undergo palatalization than voiced velars; voiced velars undergoing palatalization implies that voiceless stops do undergo palatalization.

Wilson's (2006) experiment tested whether English adults have a bias towards the implicational hierarchy. In his study, participants were exposed to a language game in which participants were trained to palatalize velars before either a high front vowel [i] or a mid front vowel [e]. Those who were exposed to the high vowel were not exposed to the mid vowel and vice versa. At test, participants were asked to repeat the language game. This time, they were given both high and mid vowels. The hypothesis was that if speakers have a cognitive bias towards the implicational hierarchy, speakers who were exposed to mid vowels during training should palatalize to high vowels at test, but speakers who were only exposed to high vowels should be less likely to generalize to mid vowels. The results demonstrated that speakers who were exposed to mid vowels generalized to high vowels, but participants who were exposed to high vowels did not. These results are in line with the hypothesis that there is a cognitive bias towards the universal implicational hierarchy for velar palatalization.

Peperkamp, Skoruppa and Dupoux (in press) provide further evidence for phonetically-based naturalness in rule learning. In their experiments, participants were exposed to an intervocalic voicing rule that was either natural or unnatural. In the natural condition, either all stops or all fricatives undergo intervocalic voicing, and in the unnatural condition a pseudorandom combination subsets of stops and fricatives undergo intervocalic voicing. In Peperkamp et al.'s study, the rule occurred between a determiner and a noun, as in *two apples*. Participants were trained on the semantic nature of each lexical item. Participants were given voiceless-voiced alternations between labial and velar segments, but not dental segments. For dental segments, only the non-alternating environment was provided. Participants were tested using a picture-naming task, and were given both words heard in training, as well as novel items. Results showed a higher percentage of voiceless-voiced alternations for the natural rules than the unnatural rules, suggesting that natural rules are learned more easier than unnatural rules. The authors report that participants did not extend the pattern to novel segments, suggesting that the rule was learned on a segment-by-segment level. There are a number of reasons to question this result and its interpretation. One is that participants in this study had a fairly small generalization of the rule to novel words. Application of the rule in the natural condition fell from about 50 percent for old words to 25 percent for novel words. One might expect that generalization to a novel segment will occur less often than to old and novel items with familiar segments, even if participants learned the rule in terms of natural classes. In this experiment, there may be a floor effect for the generalization to novel segments.

It is also possible to test infants' learning biases by testing their preference for particular phonological alternations. If the infants prefer natural alternations, it suggests an attentional bias that may lead learners to prefer these patterns in learning over unnatural patterns (Davidson, Smolensky, & Jusczyk, 2004; Jusczyk, Smolensky, & Alloco, 2002). In a series of studies, English-speaking infants were exposed to triads of speech in which the third unit was a concatenation of the first two. The concatenations either obeyed a markedness constraint on nasal place assimilation (e.g., /an/, /pa/, [ampa]), or a faithfulness constraint on the place of articulation of the nasal consonant (e.g., /an/, /pa/, [anpa]). Using the head-turn preference procedure (Kemler Nelson, Hirsh-Pasek, Jusczyk, & Cassidy, 1989), infants looked longer at the triads that conformed to the natural pattern (nasal place assimilation), suggesting that infants are sensitive to markedness constraints from a very young age. If infants are aware of natural linguistic patterns, they may use these natural patterns to guide their learning, and therefore be biased towards learning natural grammars.

6.4.2 Null Results in Naturalness Studies

While there are several grammar learning experiments that suggest a bias towards phonetically natural patterns, there are also many reported studies that report a null effect for naturalness (Peperkamp & Dupoux, to appear; Pycha et al., 2003; Seidl & Buckley, 2005, 2006). For example, Pycha et al. (2003) found no difference in learning for phonetically natural vowel harmony compared to phonetically unnatural disharmony. Further, several artificial grammar learning experiments use patterns that test general pattern learning have no phonetic naturalness (Conway & Pisoni, 2007; Gomez & Gerken, 1999; Kersten & Earles, 2001; Onnis, Monaghan, Richmond, & Chater, 2005; Saffran, Aslin, & Newport, 1996; Saffran, Reeck, Niebuhr, & Wilson, 2005; Toro, Sinnett, & Soto-Faraco, 2005) including non-linguistic grammars, such as tones and colors (Conway & Christiansen, 2006; Reber, 1967, 1976; Redington & Chater, 1996). The problem with interpreting studies with a null result for naturalness is that it does not rule out the possibility that there is a bias towards natural rules. It is well-known that many languages have phonetically unnatural rules in their grammars (Anderson, 1981; Gussmann, 1986; Hellberg, 1978; Michaels, 1988), which entails that unnatural rules are learnable. If an experiment provides enough training, it may be possible to learn both the natural and the unnatural rule. The best evidence against phonetic naturalness in grammar learning is if it were possible to learn a phonetically unnatural rule but not a phonetically natural one. Such a learning pattern could only occur if the phonetically unnatural pattern were somehow privileged to the learner, which the substantively biased theory of learning predicts should never occur. As far as I am aware, no experimental result shows a bias towards the phonetically unnatural pattern. Given that there are results supporting a bias towards phonetically natural patterns, I assume that there is evidence to support to phonetic naturalness assumptions of the substantively biased learning hypothesis.

Because it is impossible to interpret a null result in comparing learning of a natural pattern versus an unnatural pattern, a better way to test for learning biases is to assess how learners infer ambiguous data. Given that unnatural patterns are learned 'in the wild' it is not surprising that many unnatural patterns are learned in an experimental setting. If we assume that the natural learning environment has many ambiguous learning situations (where multiple hypotheses are possible to describe a given set of data), then it can be possible to simulate a natural ambiguous learning situation and test for naturalness biases such that if learners are biased towards natural patterns, they should infer a natural pattern given ambiguous data. The poverty of the stimulus method takes precisely this line of aproach. In this method, participants are exposed to ambiguous training data and test biases using disambiguating data. The substantively biased learning hypothesis predicts that given an ambiguous pattern with a natural interpretation and an unnatural interpretation, the learner should infer the natural pattern. The substantively biased learning hypothesis does claim that natural patterns are learnable and unnatural patterns are unlearnable. Rather, the substantively biased learning hypothesis predicts that given ambiguous data, the learner will infer the natural pattern.

6.4.3 Evidence for Grammatically-Based Biases

This section presents evidence for learning biases beyond phonetic naturalness, specifically grammatical well-formedness and structural simplicity. I begin this section by presenting experiments that test whether learners systematically avoid unattested vowel harmony patterns. Such experiments test the assumption of Optimality Theory that unattested grammars should both be unlearnable and ungenerated. One of the first experiments to test the assumptions of Optimality Theory investigated whether learners are sensitive to the transitivity assumption of constraint interaction in Optimality Theory (Guest, Dell, & Cole, 2000). By transitivity, if constraint A outranks constraint B, and constraint B outranks constraint C, then constraint A must outrank constraint C. This assumption was tested using an artificial language paradigm in which the mini grammar followed constraints on stress. The three constraints involved were HEAVY, which mandates that heavy syllables (CV, CVC, CVV) be stressed, CLASH, which bans two consecutive stress syllables, and ALIGN-FOOT-LEFT which requires that the initial syllable be stressed. These constraints cannot all be satisfied simultaneously. For example, if a word contains two consecutive heavy syllables and if both are stressed, HEAVY is satisfied, but CLASH is violated. If only one of the syllables is stressed, then HEAVY is violated. In such a situation, the ranking of the constraints decides which syllables to stress. If CLASH >> HEAVY, only one syllable will be stressed, but if HEAVY >> CLASH, both syllables will be stressed.

Guest et al.'s study is an attempt to address the nature of representation of adult learners of an artificial grammar and tested whether learners form representations that are compatible with Optimality Theory. If learners have posited a representation compatible with an OT grammar, they should form a representation consistent with a ranking of constraints that satisfies the transitivity assumption. Knowing that constraint A >> B, and B >> C should lead learners to infer than A >> C. In this experiment, participants were exposed to an artificial language that gave evidence for the ranking of A >> B and B >> C, but not A >> C. Participants were then tested for generalization of the rule such that constraints A and C were pitted against each other. If participants actually learned an OT grammar, their performance should match what would be expected by the ranking of A >> C. Results provided evidence that learners used transitivity in their productions of novel words from the artificial language. However, participants were equally likely to produce forms that conformed to a templatic structure for stress (e.g., always stress first and penultimate syllable) that resembled the lexical items heard during training. While participants did not appear to follow the constraints (CLASH, HEAVY, etc.), it is not the case that participants learned something inconsistent with an OT grammar. Rather, it appears that the participants learned a different grammar (i.e., one based on templatic stress structure) whose constraints outranked the constraints that the experimenters had in mind. These results suggest that there are many different mechanisms that govern how adult learners generalize to novel forms, and that experimenters must be cautious in designing artificial grammar learning experiments so that the results will tell us something about the nature of what the learner has inferred from the training data.

Guest et al.'s experiment illustrates that it is possible to test the assumptions that learners make regarding ambiguous training data. Rather than making a priori assumptions about the precise nature of the constraints that learners use, I test for the type of biases that are present in learning. Testing for a better understanding of learning biases will shape our understanding of representations for linguistic structure.

Maye et al. (2002) provide evidence for the use of statistical distributions to aid category learning. In their study, 6 and 8-month-old infants were exposed to a VOT (voice onset time) continuum for voiceless unaspirated and voiced alveolar stops [t] and [d]. Infants were either exposed to stimuli in which the continuum was constructed in a unimodal distribution or exposed to a bimodal distribution. The unimodal distribution of

VOT resembles the type of distribution that is found in languages with no phonemic voicing distinction, while a bimodal distribution reflects languages that have phonemic voicing contrasts. Maye et al. tested to see whether infants make use of the distributional statistics in order to form categories. The hypothesis was that if infants do use this information, only the infants exposed to the bimodal VOT distribution would show a categorical distinction between [t] and [d]. Discrimination was tested comparing looking times to alternating versus non-alternating stimuli. Alternations were made from both ends of the continuum. If the infant has a category distinction, they should notice the difference between alternating and non-alternating stimuli, but if the infant has formed a single category, they should treat alternating and non-alternating stimuli in the same manner. Only the infants in the bimodal condition showed longer looking times at non-alternating trials; infants in the unimodal condition had no difference in looking times. These results suggest that infants are able to form categories from distributional information. Unimodal distributions result in a single category, parallel to non-phonemic or allophonic distinctions while bimodal distributions form phonemic categories.

Many experiments using artificial languages exploit statistical properties of language to answer questions about the language learning process. One very successful paradigm for studying statistical learning is the segmentation paradigm (Aslin, Saffran, & Newport, 1997; Gomez & Gerken, 1999; Newport & Aslin, 2004; Saffran, 2003a; Saffran et al., 1996; Saffran, Newport, Aslin, Tunick, & Barrueco, 1997). In this paradigm participants, both infant and adult, are exposed to a continuous stream of artificially produced speech. The speech is made up of 3-syllable words, but are linked together without pausing, simulating the segmentation problem that language learners must face when they first confront the task of segmenting speech. In the segmentation paradigm, word boundaries are defined by the transitional probability from one syllable to the next. For example, the syllable [ki] will follow [ba] 100% of the time in the word [bakipe]. Because the order of presentation of words changes, the probability that [de] will follow [pe] in the sequence bakipe dekipe is less than 100% because sometimes the learner will hear bakipe followed by some other word. If learners can implicitly "pick up" on these transitional probabilities, then they should be able to figure out word boundaries. Segmentation is tested through a force-choice task. Participants are given a word and a part-word, both of which were presented in the training an equal number of times. They are asked to choose which of the pair is a word through the forced-choice task. If participants were able to segment the speech, they should be significantly above chance. The result is a robust one; learners consistently perform above chance. This general experiment has been performed on both adults and children.

The finding that both infants and adults can use transitional probabilities to segment speech has been extended to test questions regarding the nature of language acquisition and learning biases both in terms of segmentation and beyond (Aslin et al., 1997; Bonatti, Pena, Nespor, & Mehler, 2005; Curtin, Mintz, & Christiansen, 2005; Newport & Aslin, 2004; Pena, Bonatti, Nespor, & Mehler, 2002; Saffran, 2001, 2002, 2003b; Saffran et al., 1996; Shukla, Nespor, & Mehler, 2007; Suomi, McQueen, & Cutler, 1997; Toro et al., 2005; Vroomen, Tuomainen, & deGelder, 1998). For example, Newport and Aslin (2004) used the segmentation paradigm to test whether learners can calculate statistics based on long-distance dependences. They found that learners could not segment based on long-distance dependencies over segments but could segment with long-distance dependencies based on the syllable. In the case of the long-distance dependencies based on syllables, words were formed based on a template, such that the vowels in each syllable had to come from a distinct group of vowels, much like vowel harmony. Interestingly, the group of vowels did not form a natural class in any linguistic sense; the vowels in each group were arbitrary and random.

Pycha et al. (2003) used an artificial language paradigm to test for differences in phonological versus phonetic naturalness in vowel harmony. In their experiment, participants were exposed to stem-suffix pairs in which the suffix had allomorphs that varied by backness. This simulated palatal vowel harmony in that the suffix allomorph was conditioned by the vowels in the stem. In the harmony condition, front vowels triggered the front vowel suffix; in the disharmony condition, back vowels triggered the suffix containing the back vowel. Pycha et al.'s experiment also contained an arbitrary condition. In this condition, an unrelated set of vowels conditioned each allomorph. Participants were first exposed to stimuli that was grammatical for their condition, and then presented with two lexical decision tasks. The first task gave explicit feedback as to the grammaticality of the test item; the second task gave no feedback. Both decision tasks contained both items heard at training and novel items. Results showed poor performance in the arbitrary condition, but equally high performance in the harmony and disharmony conditions. These results suggest that learners are better able to learn phonologically natural patterns over arbitrary rules.

One possible concern about this study is the explicit nature of the learning and test tasks. In training, participants were explicitly told that they would hear singular-plural pairs, and that their task was to learn how to make plural forms. They were also given explicit feedback in the first test block. The explicit nature of the task may have caused participants to use different strategies than they otherwise might have in a more implicit task and therefore may not truly reflect linguistically-based learning biases.

Moreton (2008; in prep; in press) used the artificial grammar learning paradigm to uncover grammatical biases in learning. In his experiments, Moreton pitted two processes that have equivalent phonetic precursors (vowel height to consonant voicing dependencies and vowel height dependencies), but are distinct in their typological frequencies (Moreton, 2008). Height-voice dependencies are far less common than height-height dependencies. This is largely due to formal properties of the representations of features, such that vowel-to-vowel dependencies are much easier to capture in the phonological representations. In his experiments, Moreton trained participants on novel lexical items that had either a phonotactic constraint in which the vowel height of the second vowel was dependent on the height of the first vowel, or a phonotactic dependency in which the height of the first vowel determined the voicing of the following consonant. All participants were tested on their learning of the patterns using a forced choice test in which one item conformed to the height-height pattern and the other item conformed to the height-voice pattern. Participants who were trained with the grammatically natural height-height pattern showed more robust learning than participants who were trained on the height-voice dependency. Because both patterns share the same phonetic precursors, the best explanation for the difference in learning patterns is the difference in grammatical naturalness: height-height dependencies are grammatically natural whereas height-voice patterns are grammatically unnatural. This asymmetry is reflected in the typology of the world's languages, suggesting that grammatically-based learning biases shape the typology of the world's languages.

6.5 Overview of the Experiments

There are 12 experiments presented in this dissertation over 6 chapters. All of the experiments involve the artificial grammar learning paradigm in adults and all use vowel harmony as the grammatical process. The majority of the experiments use back/round harmony, while a few use height harmony and one uses backness harmony (without the round feature). The first sets of experiments test predictions specifically related to myopia: majority rules and sour grapes. Chapter 7 presents two experiments testing for a majority rules bias for vowel harmony languages, while Chapter 8 tests for a sour-grapes bias for vowel harmony languages. Chapter 9 tests for grammatically based biases for vowel harmony languages, specifically feature-based and morpheme-general representations for phonological processes. Chapters 10 and 11 test for phonetically-based biases for the typology of round harmony (Chapter 10) and the typology of height harmony (Chapter 11). Chapter 12 tests for biases for directionality (right-to-left over left-to-right) biases in spreading in stem controlled harmony systems and affix-controlled harmony systems. The results of these experiments support the substantively-based learning hypothesis that the typology of phonological processes is grounded in learning biases.

Chapter 7: Majority Rules (Experiments 1-2)[12]

The experiments presented in this dissertation address the hypothesis that typological restrictions on languages are due to learning biases. One of the major goals of generative linguistics is to produce a theory of language that can generate all possible languages without predicting languages that are unnatural in that they lie outside the scope of the human capacity to learn. In order to achieve this goal, the nature of language must be understood with regard to the distinction between linguistic patterns that are outside the range of possible grammars and patterns that are accidental gaps, and simply have not been documented. This difference becomes crucial when evaluating theories of generative linguistics that predict linguistic patterns that have never been observed in the set of natural languages. Specifically, grammars generated within Optimality Theory (OT) (Prince and Smolensky, 1993/2004) produce a factorial typology of all linguistic patterns predicted by the given grammatical theory. All optimality theoretic grammars are predicted to be within the cognitive capacity of language users.

The substantively biased theory of learning (Finley and Badecker, in press; Wilson, 2006) provides a promising means for understanding the relationship between grammars generated by linguistic theories and the characterization of patterns observed cross-linguistically. This theory of language learning hypothesizes that learning biases shape the distribution of linguistic patterns across the world's languages. The easiest patterns to learn are consequently the most common cross-linguistically. Patterns that are phonetically grounded and/or formally concise are the easiest patterns to learn, and therefore the most likely to appear cross-linguistically, while patterns that lack these

[12] This chapter is a modified version of (Finley & Badecker, in press-a).

properties are avoided by the learner and are therefore cross-linguistically rare. In phonology, these learning biases are grounded in both phonetic naturalness as well as phonological naturalness. For example, learners are biased to form grammars that maximize perceptual salience and articulatory ease, but they will also be parsimonious in terms of the formalization of the grammar. These formal restrictions are characterized in terms of grammatical constructs such as natural classes and formal implementation (e.g., number of rules or constraints required to characterize the grammar); they may also include non-linguistic factors that influence language processing such as working memory and attention.

While the substantively biased theory of learning offers a means for explaining the relationship between frequently occurring and unattested linguistic patterns, there is little concrete evidence to support the notion that learning biases shape the cross-linguistic distribution of patterns in the world's languages. Specifically, traditional methods for understanding the nature of linguistic typologies are limited to exploring attested patterns, and typically focus on frequently occurring or natural patterns. Because it is impossible to study how learners in a natural setting will cope with an unattested pattern, it is unclear why learners ultimately avoid particular unattested patterns. It may be that with exposure to the proper learning data, learners may be equally accommodating toward outwardly unnatural, unattested patterns as frequently occurring, natural patterns.

Because traditional methods cannot address the ways in which learners interpret unattested patterns, this paper employs the artificial grammar learning paradigm (Finley and Badecker, in press-b; Reber, 1967; Wilson 2006) in order to address the question of how learners deal with data that is ambiguous between naturally occurring patterns and unattested patterns. In the artificial grammar learning paradigm, the experimenter can control the data that the learner is exposed to, making it possible to investigate the nature of learning biases towards natural versus unnatural patterns as well as attested versus unattested patterns. According to the substantively biased learning hypothesis, a learner who is presented with language data that is ambiguous between a naturally occurring pattern and an unnatural or unattested pattern will infer the naturally occurring pattern. In the artificial grammar learning setting, it is possible to directly manipulate the learning data such that it contains precisely this ambiguity. If learners conform to substantive biases, when confronted with data that is ambiguous between an attested pattern and unattested pattern, they will postulate an attested pattern.

This chapter tests the assumptions of the substantively biased learning hypothesis in terms of vowel harmony, a phonological pattern in which all vowels in a lexical item share the same feature value (e.g., if the first vowel in a lexical item is front ([i, e]) all other vowels in the word must also be front ([i, e])). Vowel harmony is an ideal phonological pattern to test the substantively biased learning hypothesis for several reasons. First, vowel harmony is an extremely common phonological pattern that occurs in a wide range of language families (e.g., Bantu, Nilotic, Romance, Uralic) (Clements, 1976; Kiparsky 1981). Second, vowel harmony is widely studied and the typology of vowel harmony is relatively well agreed upon among linguists, making it possible to assess which vowel harmony patterns are natural and which are unattested (Nevins, 2004). Finally, vowel harmony is ideal for an artificial grammar learning experiment because English does not have vowel harmony, and is relatively exotic to the typical native speaker of American English. Vowel harmony can therefore be taught to our participants without worry of prior knowledge or obscurity of the phonological pattern we are testing.

Vowel harmony is a spreading process according to which a single vowel will serve as the harmony trigger- and will thereby determine the feature value of all other vowels in the word. Apart from morphological influences on vowel harmony, there are two main factors that determine how the trigger for harmony is determined: directionality and dominance (Bakovic, 2000; Nevins, 2004)[13]. In directional harmony systems, either the leftmost vowel spreads its features rightward (e.g., /+ – –/ ⇒ [+ + +]; /– + +/ ⇒ [– – –]) or the rightmost vowel spreads its feature value leftwards (e.g., /+ + –/ ⇒ [– – –]; /– – +/ ⇒ [+ + +]). In dominant systems, the harmony trigger is determined by the presence of a vowel with a particular feature value (e.g., [+F]). If such a vowel is present, the feature will spread bi-directionally (e.g., /– + –/ ⇒ [+ + +]).

However, there are no languages in which the harmony trigger is determined by the relative number of vowels in the input with a particular feature value. This type of unattested pattern, termed 'majority rules' (Lombardi, 1998), hypothetically occurs when the trigger for harmony is determined by the feature value in the input that will allow for all vowels to share the same feature value, but with the fewest possible changes to the input. For example, if the input contains two [+F] vowels and one [–F] vowel, the output will have three [+F] vowels (/+ – +/ ⇒ [+ + +]), but if the input contains two [–F] vowels and one [+F] vowel, the output will be [–F] (e.g., /– – +/ ⇒ [– – –]), regardless of the direction of harmonic spreading.

[13] Another type of harmony pattern, not discussed, is stress-triggered harmony in which the feature value of the stressed vowel spreads throughout the lexical item. This can be considered a form of dominance because spreading is bi-directional.

While such patterns are unattested, they are very easily generated in grammatical systems like Optimality Theory (Bakovic 1999, 2000; Lombardi, 1998). With a constraint that only requires output vowels to share the same feature value (e.g., AGREE[F]), it is possible, with a markedness, faithfulness interaction to predict a language in which all outputs are harmonic, but the harmonic trigger is determined by the majority feature value, because that majority feature value will produce the fewest violations of faithfulness. This is illustrated in the hypothetical tableau in (152).

(152) AGREE >> ID

/bɪnigi/	AGREE[ATR]	ID[ATR]	*[+ATR]	*[–ATR]
[bɪnigi]	*!		**	*
[bɪnɪgɪ]		**!		***
☞ [binigi]		*	***	

The uniformly [+ATR] candidate [binigi] is the winning output of the optimization in (152) because it has the fewest ID[ATR] violations while still satisfying the higher-ranked AGREE constraint: there are two [+ATR] vowels and only one [–ATR] vowel in the input. Had the input contained two [–ATR] vowels and one [+ATR] vowel (e.g., /bɪnɪgi/), the optimal output would have been the [–ATR] candidate [bɪnɪgɪ]. The markedness-faithfulness interaction of OT, along with a harmony constraint that does not require dominance or directionality, can produce harmony systems in which any harmonic output will surface with the least number of changes to the input. If the harmony inducing constraint only requires agreement, then the harmonic item with the fewest faithfulness violations will emerge, producing an unattested majority rules grammar.

The question, then, is whether the fact that majority rules grammars are easy to produce should be a problem for the analyst. While Lombardi (1998) and Bakovic (1999,

2000) have found solutions to avoiding majority rules grammars in analyses that make use of non-directional AGREE-type harmony constraints, there is still the worry that the ease of generation of such grammars implies that majority rules grammars should be available to the cognitive learning apparatus. It is also possible that majority rules grammars may be entirely plausible from the standpoint of the grammatical system and the fact that there are no majority rules languages is due to an accidental gap in grammars that can produce such majority rules languages.

One way to distinguish between a principled restriction on the nature of vowel harmony languages and an accidental gap account is through testing for learning biases for both majority rules languages and attested harmony languages, specifically directionally-induced harmony languages. If learners are biased against majority rules languages in favor of attested directional harmony system, then it suggests that the non-existence of majority rules languages is a real restriction on grammars. Because it is impossible to test learning biases for unattested languages in a naturalistic setting, as there are no naturalistic settings where a majority rules grammar might be present, the artificial grammar learning paradigm is the best method for addressing this question.

Experiment 1A-Pilot

Experiment 1A tests for the learnability of a majority rules pattern as compared to an attested pattern of round dominance. The hypothesis is that if learners are biased against the unattested majority rules pattern, they should show greater learning for the attested round-dominant patterns than for the unattested majority rules patterns.

This experiment involves three training conditions and a Control condition. In the Control condition, participants are exposed to stems in their disharmonic state, but without their harmonic concatenation. The three training conditions are: Majority Rules, Myopic (round dominant) and Ambiguous (round dominant). In the Majority Rules condition, participants are trained on a majority rules pattern. If the input contains two round vowels and one unround vowel, the output will be round; if the input contains two unround vowels and one round vowel, the output will be unround, regardless of the direction of spreading. In the Myopic condition, participants are trained that the harmonic output will always be round if the input contains at least one round vowel, no matter how many unround vowels are in the input. In the Ambiguous condition, participants are trained that if there are two round vowels and one unround vowel in the input then the output will be round. The Ambiguous condition is called as such because the round output could be a result of a majority rules rule or a round-dominant rule.

The hypothesis for this experiment is that if participants learn the myopic pattern over the majority rules pattern, they are biased against majority rules. In the ambiguous condition, participants were asked to generalize to cases where round is the minority (two unround, one round vowel). If their bias is towards majority rules, then they should prefer unround harmonic, but if they are biased towards a round dominant-rule, they should prefer the round harmonic.

Method

Participants

All participants were adult native English speakers with no knowledge of a vowel harmony language. Fifty-six Johns Hopkins undergraduate students participated for extra course credit. Participants were randomly assigned to one of three training groups: a Control condition containing mixed harmony stems, a High Vowel Suffix condition and

Mid Vowel Suffix condition. Final analyses included 13 participants in each of four conditions.

All participants were screened based on a perceptual task to ensure that they could discriminate between round and unround vowels (of the same height, high and mid counterparts). In this simple AXB perception task, participants were asked to judge which of two vowel sounds was identical to a third sound. For example, if participants heard [be], [be] and [bo], the correct response would be [be]. All items were monosyllabic. The task was designed as a way to screen participants for the ability to perceive round-unround contrasts in English. Those participants scoring less than 75 percent on this task were removed from the study, with the logic that we assume that all participants should have general competence for perceiving English vowels in order for their learning data to be meaningful. This occurred for four participants.

Design

There were 13 participants in each of four training conditions: a Myopic (round-dominant) condition, a Majority Rules condition and an Ambiguous condition and a Control condition.

The experiment consisted of a training phase followed immediately by a forced-choice test. All phases of the experiment were presented using PsyScopeX (Cohen, MacWhinney, Flatt, & Provost, 1993).

Because the experiments are testing the nature of learning in an artificial grammar setting, it is necessary to ensure that the effects that we find are actually due to learning, rather than a prior bias, or bias in selecting particular items (Redington & Chater, 1996). We created Control conditions to ensure that all effects were due to specific learning strategies. One option for a Control condition is to give these participants no training data at all, and simply give test items to these participants. However, we do not feel that this is an adequate Control for the present experiment for two main reasons. First, the participants in this task would require very different instructions. As they would have no training to base their responses, they would have to be given some background, which would result in very different test instructions for these participants, which may influence the results. Second, having no basis for response, participants may use a strategy that is entirely different from any strategy that participants in the training conditions might employ. Our solution was to give the controls the underlying forms (mono-syllabic items). This would give them a sense of how the language sounds, but no basis for how the monosyllabic items should be concatenated together. Any responses will be based solely on their bias for one type of concatenation over another.

Finally, no explicit feedback was given to participants. While any artificial language task contains some level of arbitrariness, leaving out explicit feedback makes the learning as close to a natural setting as possible and helps to minimize the use of explicit learning strategies.

Materials

Because majority rules effects are the result of faithfulness determining which harmonic candidate is optimal, the input must be given to the participants so that the learner can calculate faithfulness to the underlying form. The stem-suffix alternations presented in previous experiments, and the majority of experiments to be presented in this dissertation do not explicitly give an underlying form. For example, the alternation between [-mi] and [-mu] does not make it clear whether [-mi] is the underlying form or

[-mu], and there is no obvious way to detect what participants perceive as the underlying form (if anything). Therefore, for this experiment we did not use a stem-suffix alternation. Rather, participants were given three single syllable forms in isolation, followed by their harmonic concatenations. For example, [pu], [gi], [do] is concatenated as [pugudo], where all vowels are round. Participants heard the three isolated syllables, which was followed by the concatenated form together after a 500ms pause.

There were 24 sets of single syllable words followed by the tri-syllabic concatenation. All items were drawn from a set of 4 vowels ([i, u, e, o]) and 8 consonants ([p, t, k, b, d, g, m, n]). The harmony rule paired back/round vowels together such that a harmonic trisyllabic item contained all front vowels ([i, e]) or all back vowels ([u, o]). The three individual syllables were disharmonic such that their faithful concatenation would be disharmonic (e.g, [pi] [bo] [di]). The concatenation form either followed majority rules ([bibedi]) or followed a round-dominant pattern. In the Majority Rules condition, all items followed majority rules, but in the Myopic condition, all items followed the round-dominant pattern.

Whether the concatenated form contained all round or all unround forms on the condition. In the Control condition, participants were not exposed to any concatenated forms; they were only exposed to the 3-syllable sets in isolation. In the Majority Rules condition, half of the alternating sets contained two round and one unround vowel and the other half contained two unround and one round vowel. All concatenations showed the minority vowel changing, following the principle of majority rules pattern, with the majority feature value dictating the direction of change. In the Myopic condition, half of the alternating sets contained two round and one unround vowel; the other half contained two unround and one round vowel. All concatenations showed the unround vowel changing, following myopia. In the Ambiguous condition, all of the alternating forms contained two round and one unround vowel, and the change always involved the unround vowel changing to round. All stimuli were recorded in a sound proof booth at 22,000kHz by a male speaker of American English with basic phonetic training (had completed a graduate-level phonetics course). While the speaker had no knowledge of the specifics of the experimental design, he was aware that the items would be used in an artificial language learning task. All stimuli were phonetically transcribed, and presented to the speaker in written format. The speaker was instructed to produce all vowels as clearly and accurately as possible, even in unstressed positions. Stress was produced on the first syllable. Examples of training stimuli are in (153) below.

(153) Examples of Training Stimuli: Experiment 1A

Majority Rules	**Myopic**	**Ambiguous**
[bo du tu, bodutu]	[bo di ti, bodutu]	[bo du ti, bodutu]
[di pe be, dipebe]	[di pe be, dipebe]	[di pe be, dipebe]
[go mi to, gomuto]	[ge mu to, gomuto]	[ge mu to, gomuto]
[ku mo te, kumoto]	[ki me to, kumoto]	[ku mo te, kumoto]
[mo nu ko, monuko]	[mo ni ko, monuko]	[mo ni ko, monuko]
[no pi be, nepibe]	[ne pi be, nepibe]	[ne pi be, nepibe]
[pi to ne, putono]	[pi te ne, pitene]	[pi te ne, pitene]
[ti pi nu, tipini]	[ti pi ni, tipini]	[ti pi ni, tipini]

All sound editing was done using Praat (Boersma & Weenink, 2005). All stimuli contained the same consonant inventory: [p, b, t, d, k, g, m, n]. The vowel inventory for all conditions consisted of [i, u, e, o]. The training stimuli were counterbalanced to contain all possible combinations of vowel sounds. Consonants were also counterbalanced such all consonants appeared equally often in each position. Concatenated words were produced semi-randomly with the condition that any word too closely resembling an English word was intentionally avoided (the final profile of the stimuli was counterbalanced to appropriately contain equal numbers of consonant pairs and a consistent number of vowel pairs). Examples of test stimuli appear in the table in (154) below. Full stimuli lists are provided in Appendix I.

(154) Examples of Test Stimuli: Experiment 1A

Ambiguous		**Majority Rules**		**Myopic**	
bekotu	Old	bineke	Old	bineke	Old
dipebe	Old	dipebe	Old	dipebe	Old
kebipi	Old	kebipi	Old	kebipi	Old
mukibo	Round	mukibo	Round	mukibo	Round
nopeko	Round	nopeko	Round	nopeko	Round
podobe	Round	podebo	Round	podebo	Round
nipuki	Unround	nipuki	UnRound	nipuki	Unround
pimute	Unround	pimute	UnRound	pedomi	Unround
timune	Unround	timune	UnRound	tikope	Unround

Procedure

All participants were given written and verbal instructions. They were told that they would be listening to a language they had never heard before, and that they would later be asked about the language, but they need not try to memorize any forms they heard. No information about vowel harmony or about the morphology of the language was given. No semantics accompanied the sound pairs. Participants heard all stimuli over headphones. Participants were given the underlying form before the concatenated harmonic form. Three individual single syllable items were presented followed by their harmonic concatenation. There were 24 items for each participant, each repeated 5 times in a random order.

Training was followed by a forced-choice test phase in which participants heard the three single-syllable input followed by a choice of harmonic concatenations: all round or all unround. If the first concatenation of the syllables belonged to the language, they must push the ‘a’ key on the keyboard; if the second concatenation of the syllables belonged to the language, they must press the ‘l’ key on the keyboard. Participants were told to respond as quickly and accurately as possible, and to make their responses after hearing both items. Following the test phase, participants were given an AXB perception task for the vowels heard in training. For example, participants heard three single syllable items. If the first vowel was identical to the second vowel, participants were instructed to press the ‘a’ key (e.g., [pi] [gi] [mu]); if the second vowel was identical to the third vowel, participants were instructed to press the ‘l’ key (e.g., [mu] [gi] [pi]).

Participants were given a debriefing statement upon completion of the experiment (which took approximately 15 minutes).

Results

Percent of round responses were recorded for each subject for each of the training conditions. The mean responses for each test condition are presented in the figure, in (157) below. The graph represents the proportion of responses where the participant chose a round item. When the majority of vowels in the input are round, a high response rate is expected for both the round dominant (myopic and ambiguous) and the majority rules cases. When the majority of the vowels in the input is unround, a high proportion of round response is expected in the myopic condition, and a low proportion of responses is expected in the majority rules condition.

To assess learning, ANOVAS were performed comparing each condition to the Control condition. We also compared the Majority Rules and the Myopic condition to assess whether there was more majority rules effects in either condition. For the ANOVA comparing the Majority Rules condition with the Control, there was no effect of Training

(F < 1), no effect of Test Item (F < 1) and no interaction ($F(2, 48) = 1.52$, $p > 0.05$). For the ANOVA comparing the Ambiguous Condition and the Control, there was an effect of Training (0.81 vs. 0.69, *CI* = 0.11; $F(2, 1) = 5.47$, $p < 0.05$). There were no effects for Test Item (F < 1) and no interactions (F < 1). For the ANOVA comparing the Myopic condition and the Control, there were no effects for Training (0.66 vs. 0.69, *CI* = 0.05; F <1), Test Item (F < 1), or interaction ($F(2,48) = 1.81$, $p > 0.05$). For the ANOVA comparing the Myopic and the Majority Rules conditions, there was no effect of Test Item (0.74 vs. 0.69, *CI* = 0.14; $F(2, 12)=2.39$, $p > 0.05$) or Training ($F(1,12)=2.0$, $p > 0.05$). There was, however, a significant interaction ($F(2,48)= 3.59$, $p < 0.05$), reflecting the larger proportion of majority rules responses in the Old Condition for the Majority Rules condition.

To assess whether learners had a majority rules bias, contrasts were performed for each condition, comparing the proportion of round responses when the majority of input vowels were round, and when the majority of input vowels were unround. A significant response indicates a majority rules bias because in majority rules, there should be more round responses when the majority of the input vowels are round than when they are unround. All conditions showed a significant difference in round responses depending on the number of round vowels in the input, indicating majority rules. As expected, there was also a significant difference in Majority Rules condition, ($F (1, 12) = 13.52$, $p < 0.01$). Surprisingly, there was also an effect in the Control condition ($F (1, 12) = 1395$, $p < 0.01$), as well as in the Myopic condition ($F (1, 12) = 9.04$, $p < 0.05$). There was also a significant difference for majority round versus unround in the Ambiguous condition ($F (1, 12) = 50.97$, $p < 0.001$).

Discussion

Participants show a strong majority rules preference, as evidenced by the fact that even participants in the Control and Myopic conditions demonstrated a strong majority rules strategy. However, this result may not be a majority rules bias, but a bias for faithfulness to the initial syllable. In the majority of test items, the initial syllable shared the same feature value as the majority feature value. It is therefore possible that participants responded to the majority item not out of a majority rules bias, but because the majority item had an identical initial syllable as the input.

It may be that learners were biased towards faithfulness to the initial syllable because the alternation from input to output was unlike natural harmony languages, and therefore appeared arbitrary. One possibility for getting around the initial-syllable faithfulness bias in learners would be to make the change from input to output less arbitrary and more like a morphophonologically conditioned alternation. In previous experiments, morphophonological alternations involved an affixed form with allomorphs. The problem with incorporating this design into a majority rules experiment is that the input or underlying form of the alternating morpheme is never given. In order to make any inference about faithfulness violations, one has to assume that all learners are making the same assumptions about the underlying form. Another possibility is to have the stem alternate with itself as featural affixation (Akinlabi, 1996). In this case, the stem would be a disharmonic input form, and the affixed form would be the harmonic form of the lexical item. This type of harmony, referred to as morphemic harmony (Finley, 2004, 2006, in preparation) is a cross-linguistically viable type of harmony in which a morpheme is realized via vowel agreement. We re-ran the experiment as a morphological alternation, where the singular form need not be harmonic, but the plural form must agree in back/round features. For example, if the singular form is [pidogo] the plural form could be [pidege] under a left-to-right spreading rule or [pudogo] under a majority rules system. The experiment uses the same training-test procedure. However, instead of giving participants three isolated single-syllable words as the input, the form would be a single three-syllable word, explicitly told that the form was a singular item. The output would be a harmonic form of the three-syllable word, explicitly described as the plural of the first item. For example, participants would hear the singular [pidego] followed by the plural [pidege].

The design of the experiment is also improved by eliminating the Majority Rules and the Myopic conditions and creating two Ambiguous conditions. In the first Ambiguous condition, harmony would spread left to right where the first two vowels of the input would be round and the final vowel would be unround. For example, the input /pudoge/ would surface as [pudogo]. In the second Ambiguous condition, spreading would proceed from right to left, such that the initial vowel is unround but the final two vowels are round; the input /pidogo/ would surface as [pudogo]. At test, participants in the right to left Ambiguous condition would be tested on majority rules stimuli spreading from left to right (e.g., /pudege/). Half of the items would have the majority of the vowels in be round and the other half would be unround. This would prevent results reflecting something ambiguous between a round bias and a majority rules effect (if all the items had majority round, then it would be impossible to differentiate between round dominance and majority rules).

By treating the harmony process as a morphophonological operation as opposed to a result of concatenating three isolated words, the process will hopefully be more language-like, and draw attention away from the number of segments that are changing, and what the process is. Additionally, compounds in harmony languages tend to be exempt from harmony rules. Since the concatenation of the three syllable items in the pilot closely resembled compounding, it may have lead to difficulty for participants to enforce vowel harmony on the concatenated morpheme. There may also be a general tendency for whole words in concatenated forms to be kept as close to their original concatenated form as possible.

Experiment 1: Majority Rules versus Directionality

Experiment 1 is similar to the pilot experiment in that participants are tested on their bias towards majority rules languages. In Experiment 1, participants are exposed either to a left-to-right harmony pattern or a right-to-left harmony pattern in which the majority of the vowels in the input spread. If participants learn a majority rules pattern, they will reverse the direction of spreading when the majority of vowels reverse, but if participants learn a directional pattern, they will select the minority pattern as long as the direction remains the same.

Method

Participants

All participants were adult native English speakers with no knowledge of a vowel harmony language. Thirty-six Johns Hopkins undergraduate students participated for extra course credit. Participants were randomly assigned to one of three training groups: a Control group containing mixed harmony stems, a Right-to-Left condition and a Left-to-

Right condition. Final analyses included 11 participants in each of three groups. All participants were screened based on a perceptual (AXB) task. Those participants scoring less than 75 percent on this task were removed from the study. This occurred for 1 participant. The data for 2 participants were not used because they had been run in previous vowel harmony learning experiments.

Design

As in the pilot study, the input needed to be transparent. Participants were exposed to morphophonological alternations. This time, the alternations were in the form of a disharmonic 3-syllable word followed by its harmonic counterpart (e.g., [pigebo] ⇒ [pigebe]). Participants received each 24 sets of single syllable words. For all sets that had some disharmony for roundness, the first and the last syllable agreed. The concatenation form either followed majority rules (the middle syllable changed) or followed a round-dominant pattern; some sets followed both constraints. The constraints that the sets of three followed depended on the condition. In the Control condition, participants were only exposed to the disharmonic forms. Participants in the critical conditions were trained on either right-to-left harmony (e.g., [pidego] ⇒ [pidege]) or left-to-right harmony (e.g, [pidogo] ⇒ [pudogo]), but all of the items were ambiguous between directionality and majority rules. That is, all of the training items showed only a single item changing from the input to the output. At test, the critical items are reversed such that spreading the majority feature value requires spreading in the opposite direction. If learners infer a directional pattern, then they will accept multiple items undergoing harmony from the input to the output. If learners infer a majority rules pattern, they will reverse the direction of spreading. Test items include 12 Old Items, 12 New Items and 12 New

Direction Items. Old and New items have the majority feature reflect direction of spreading that the participant was trained on, but the New Direction items reflect a reversal of the direction that the participants were trained on. Examples of training stimuli are in the table in (155) below.

(155) Training Stimuli: Experiment 1

Right-to-Left Training Condition	Left-to-Right Training Condition
[bedutu, bodutu]	[boduti, bodutu]
[dogibe, degibe]	[degibo, degibe]
[gebupu, gopubu]	[gopubi, gopubu]
[mogite, megite]	[megito, megite]

Following training, participants were given a forced-choice task. In this task participants were given two pairs of three-syllable items. The first member of each pair was the disharmonic form, and the second member was a harmonic form with either spreading from right-to-left or left-to-right (e.g., [pidego, pidege], [pidego, pudogo]). Participants were asked to choose which pair was the one that would fit the language they were trained on. Examples of test items are provided in the table in (156) below. The experiment finished with the same AXB perception task as in the pilot.

(156) Examples of Test Items: Experiment 1

Right-to-Left Training **Old Items**	**Left-to-Right Training** **New Direction Items**
[pumite, pimite]	[pumite, pumuto]
[kogibe, kegibe]	[kogibe, kogubo]
[nepoko, nopoko]	[nepoko, nepeke]
New Items	**New Items**
[nupiki, nipiki]	[nipiku, nipiki]
[pedobo, podobo]	[podobe, podobo]
[biteko, biteke]	[biteko, biteke]
New Direction Items	**Old Items**
[kukope, kikepe]	[kukope, kukopo]
[miketo, mukoto]	[miketo, mikete]
[nebegu, nobogu]	[nebegu, nebegi]

Stimuli

The stimuli were similar to those of the concatenated forms in the Pilot. Each form was produced by the same male speaker of American English from the Pilot. All stimuli was normalized to 70db.

Procedure

The procedure for Experiment 1 was identical to the procedure of the Pilot. Participants were told that they would be listening to pairs of words from a language they never heard before, and that their task was to listen to the way the novel language sounded, but that they need not try and memorize the forms. The training was followed by a forced-choice test with 36 items. This was followed by a perception task of English vowel contrasts.

Results

The proportion of 'majority rules' responses was recorded for each participant. If participants learned a majority rules pattern, this proportion should remain high for all test conditions. However, if participants learned a directional pattern, then the proportion of majority rules responses should be high for Old and New test items, but low for New Direction Items. A summary of the results across training and response conditions is provided below in the figure in (158).

To ensure that there was an overall effect of training for each of the conditions, a 2 (Training) x 3 (Test Condition) mixed-design ANOVA was performed, comparing the Left-to-Right and the Right-to-Left conditions with the Control condition. There was a significant effect of Training for both the Left-to-Right condition (mean = 0.57 training vs. 0.42 control, $CI = \pm 0.06$; $F(1, 20) = 11.83$, $p < 0.01$) as well as the Right-to-Left condition (mean = 0.65 training vs. 0.42 control, *CI* = ± 0.06; $F(1, 20) = 36.80$, $p < 0.001$). Both conditions learned some form of the harmony alternation.

To test whether participants inferred a directional rule versus a majority rules pattern, we performed contrasts comparing the New Direction test condition to the Old and New items respectively. Responses in the Left-to-Right condition also showed a significant difference between the New Direction and both the Old (0.78 vs. 0.23, *CI* = ± 0.30; $F(1, 10) = 20.82$, $p < 0.01$) and New (0.70 vs. 0.23, *CI* = ± 0.27 $F(1, 10) = 11.86$, $p < 0.01$) test conditions. In the Right-to-Left Condition, there was a significant difference between the New Direction and both the Old test conditions (0.86 vs. 0.25, *CI* = ± 0.26; $F(1, 10) = 34.22$, $p < 0.001$) and New test conditions (0.83 vs. 0.25, *CI* = ± 0.24; $F(1, 10) = 24.74$, $p < 0.01$). The fact that participants chose the 'majority rules' items significantly more often in the Old and New test items suggests that learners infer a directional pattern rather than a majority rules pattern, which indicates a bias *against* majority rules.

Discussion

The results of Experiment 1 suggest that learners are biased toward a directional harmony pattern over a majority rules pattern. This suggests that the 'majority rules' bias found in the pilot experiment may have been due to confounds in the test set or to the unnatural compounding nature of the training stimuli. To test whether the majority rules bias emerged out of a bias in the test stimuli or the compounding nature of the training data, we performed a second experiment in which participants were exposed to directional compounding. Experiment 2 matches Experiment 1 except that the stimuli are formed out of compounding rather than alternations.

Experiment 2: Majority Rules versus Directionality in Compounding

Experiment 2 is similar to the pilot experiment in that participants are tested on their bias towards majority rules languages. In Experiment 2, participants are exposed either to a left-to-right harmony pattern or a right-to-left harmony pattern in which the majority of the vowels in the input spread. If participants learn a majority rules pattern, they will reverse the direction of spreading when the majority of vowels reverse, but if participants learn a directional pattern, they will select the minority pattern as long as the direction remains the same.

Method

Participants

All participants were adult native English speakers with no knowledge of a vowel harmony language. 24 Johns Hopkins undergraduate students participated for extra course credit. Participants were randomly assigned to one of three training groups: a Control group containing mixed harmony stems, a Right-to-Left condition and a Left-to-Right condition. Final analyses included 8 participants in each of four groups. All participants were screened based on a perceptual (AXB) task. Those participants scoring less than 75 percent on this task were removed from the study. This occurred for no participants.

Design

As in the pilot study, the input needed to be transparent. Participants were exposed to compounding. This time, the alternations were always directional (e.g., [pi] [ge] [bo] ⇒ [pigebe]). Participants received each 24 sets of single syllable words. The concatenated form always followed majority rules, in one particular direction. In the

Right-to-Left condition the majority was always at the right edge. In the Left-to-Right condition, the majority items were always at the left edge. In the Control condition, participants were only exposed to the single-syllable forms. Participants in the critical conditions were trained on either right-to-left harmony (e.g., [pi] [de] [go] ⇒ [pidege]) or left-to-right harmony (e.g., [pi] [do] [go] ⇒ [pudogo]), but all of the items were ambiguous between directionality and majority rules. That is, all of the training items showed only a single item changing from the input to the output. At test, the critical items are reversed such that spreading the majority feature value requires spreading in the opposite direction. If learners infer a directional pattern, then they will accept multiple items undergoing harmony from the input to the output. If learners infer a majority rules pattern, they will reverse the direction of spreading. Test items include 12 Old Items, 12 New Items and 12 New Direction Items. Old and New items have the majority feature reflect direction of spreading that the participant was trained on, but the New Direction items reflect a reversal of the direction that the participants were trained on.

Following training, participants were given a forced-choice task. In this task participants were given two pairs of three-syllable items. The first member of each pair was the disharmonic form, and the second member was a harmonic form with either spreading from right-to-left or left-to-right (e.g., [pi] [de] [go] [pidege] vs.[pi] [de] [go] [pudogo]). Participants were asked to choose which pair was the one that would fit the language they were trained on. The experiment finished with the same AXB perception task as in the pilot and Experiment 1.

Stimuli

The stimuli were similar to those of the concatenated forms in the Pilot. Each form was produced by the same male speaker of American English from the Pilot. All stimuli was normalized to 70db.

Procedure

The procedure for Experiment 2 was identical to the procedure of the Pilot and Experiment 1. Participants were told that they would be listening to words from a language they never heard before, and that their task was to listen to the way the novel language sounded, but that they need not try and memorize the forms. The training was followed by a forced-choice test with 36 items. This was followed by a perception task of English vowel contrasts.

Results

As in Experiment 1, proportion of 'majority rules' responses were recorded for each participant. If participants learned a majority rules pattern, this proportion should remain high for all test items. However, if participants learned a directional pattern, proportion of majority rules responses should be high for Old and New test items, but low for New Direction Items.

To ensure that there was an overall effect of training for each of the conditions, a 2 (Training) x 3 (Test Condition) mixed-design ANOVA was performed, comparing the Left-to-Right and the Right-to-Left conditions with the Control condition. There was a significant effect of Training for both the Left-to-Right condition (0.66 vs. 0.54, CI = 0.09; $F(1, 14) = 8.90$, $p < 0.05$) as well as the Right-to-Left condition (0.63 vs. 0.54, CI= 0.08; $F(1, 14) = 5.72$, $p < 0.05$). Both conditions learned some form of the harmony rule.

To test whether participants inferred a directional rule versus a majority rules pattern, we performed contrasts comparing the New Direction test condition to the Old and New items respectively. In the Left-to-Right Condition, there was a significant difference between the New Direction and both the Old (0.42 vs. 0.83, $CI = 0.24$; $F(1, 7) = 17.07$, $p < 0.01$) and New (0.42 vs. 74, $CI = 0.24$; $F(1, 7) = 10.13$, $p < 0.05$) test conditions. Right-to-Left condition also showed a significant difference between the New Direction and the Old (0.34 vs. 0.84, $CI=0.28$; $F(1, 7) = 17.49$, $p < 0.01$) and a marginally significant difference between the New Items (0.34 vs. 0.71, $CI= 0.38$; $F(1, 7) = 5.20$, $p < 0.08$) test conditions. The fact that participants chose the 'majority rules' items significantly more in the Old and New test items suggests that learners infer a directional pattern rather than a majority rules pattern, reflecting a bias against majority rules.

Discussion

The results of Experiment 2 suggest that participants learned a directional harmony pattern over a majority rules harmony pattern, and that this bias can be found in alternations of a single form as well as from concatenations of three single-syllables. This confirms the hypothesis that the majority rules bias in the pilot experiment emerged from confounds in the stimuli and not a bias towards majority rules or an inability to infer patterns from concatenation.

GENERAL DISCUSSION:

The results of the present experiments suggest that learners have a learning bias that favors directionality over majority rules patterns. The fact that learners are biased towards directional patterns over majority rules harmony patterns gives us some insight into why majority rules patterns do not exist in natural language. If learners are not biased to infer majority rules from their language data, then it is unlikely that such a pattern would emerge. Rather, the pattern to emerge would be a directional pattern, which is what learners are biased to infer. It may be that, as myopia suggests, learners pay more attention to direction of spreading or location of the undergoer rather than the number of harmony triggers. For example, in our training data, the vowel to undergo harmony was always at either the left or right edge of the word. If learners are able to focus on this aspect of the pattern, they will be less likely to infer a majority rules pattern because their attention is pulled towards the undergoers of harmony rather than the harmony triggers. In natural language, directional harmony also works in this way; in right-to-left harmony the first vowel always alternates; in left-to-right harmony, suffix vowels always alternate at the end of the word. If learners are drawn to where alternations occur (edge of word, suffix, prefix, etc.), then they will be less likely to remember the number of vowels that triggered harmony, and should be unlikely to infer a majority rules pattern.

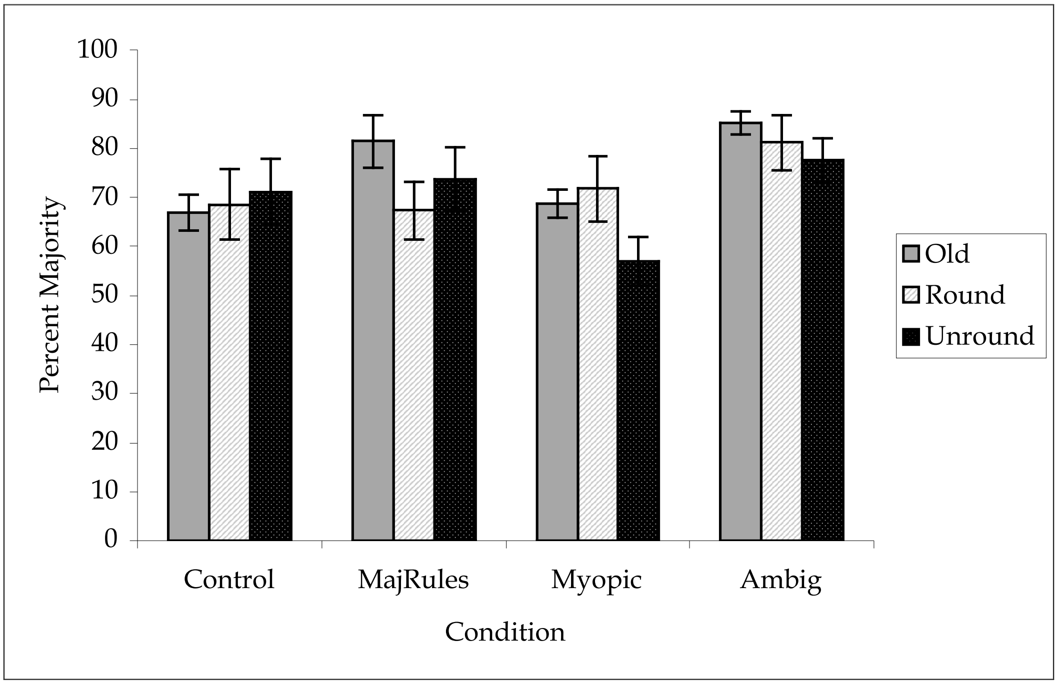
The fact that our experiments showed a directional bias over a majority rules pattern supports the theory of grammar that avoids making majority rules predictions. Not only are such languages un-attested, but learners have no bias to infer such patterns. There is a question, however, as to whether majority rules grammars really have to be excluded by the grammatical framework. If non-linguistic factors drive the bias against majority rules, then it is possible that the generative system could produce a majority rules grammar but a learner will be very unlikely to infer such a grammar given non-linguistic constraints on memory and attention. In the present experiments, a directional harmony pattern makes use of the attentional salience of the beginnings and ends of words (J. M. Beckman, 1998; Brown & McNeill, 1966; Christophe, Peperkamp, Pallier, Block, & Mehler, 2004; R. A. Cole, 1973; Marslen-Wilson, 1975). For example, in left to right spreading the first vowel of the word is always the trigger, and the final vowel of the word is always a target. If learners are biased to infer patterns based on what occurs at the beginnings and ends of words, it is likely that they will infer a directional pattern over a majority rules pattern (which is completely unreliable in terms of salience of the beginnings and ends of the words). Additionally, majority rules patterns require the learner to keep track of a wider range of conditioning factors: how many vowels of each feature value are in the input, and which direction of spreading to use when there is a tie. A majority rules pattern may require more episodic memory because several different situations in the input induce very different results. For example, two round vowels and two unround vowels may yield all round vowels, but three round vowels and four unround vowels, the output will contain unround vowels. However, if two of the four unround vowels are opaque, identity will favor the round vowels, and all round vowels will surface. While complicated patterns are not uncommon cross-linguistically, if a learner has to decide between a simpler directional pattern and a complicated majority rules pattern, they should choose the directional pattern.

One way that one might be able to determine whether the directionality preference is due to non-linguistic factors against majority rules is to replicate the present experiments but using non-linguistic stimuli. If learners of non-linguistic pattern follow the same constraints on majority rules, then it is likely that the bias against majority rules found in these experiments is due to non-linguistic factors, but if no bias is found in non-linguistic stimuli, it suggests that there is something about the linguistic nature of harmony that biases learners towards directional spreading.

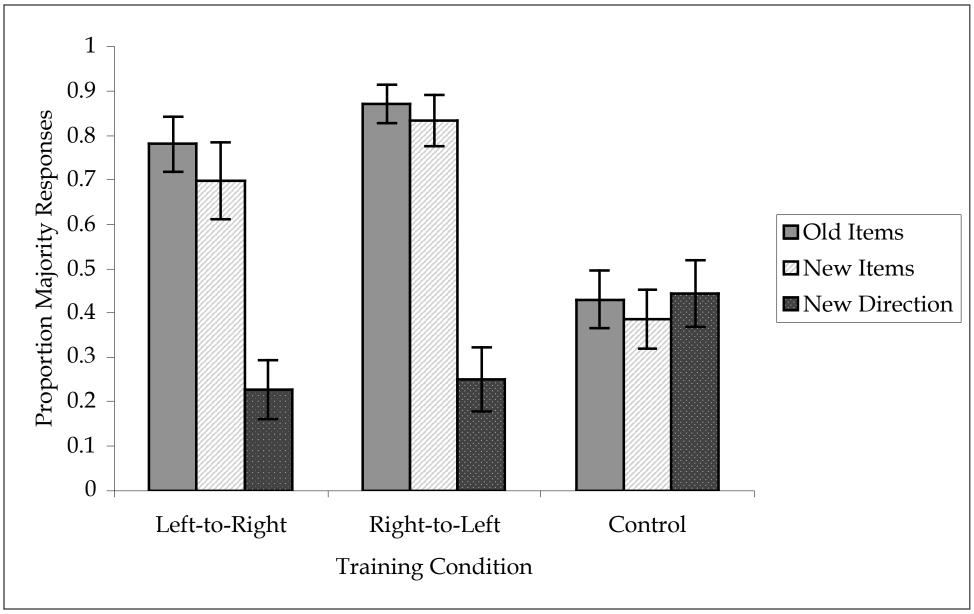
CONCLUSION

Experiments 1 and 2 support the grammar proposed in Chapters 4 that makes a point to avoid majority rules grammars, and specifically encodes directionality in harmony. It appears that learners are sensitive to the location of the undergoer rather than the quantity of harmony triggers. Future research might explore the nature of sensitivity to location and quantity of the harmony undergoer and trigger in learning by specifically controlling for these factors in the training. Additionally, it would be interesting to see if the biases found in these experiments are present in non-linguistic materials.

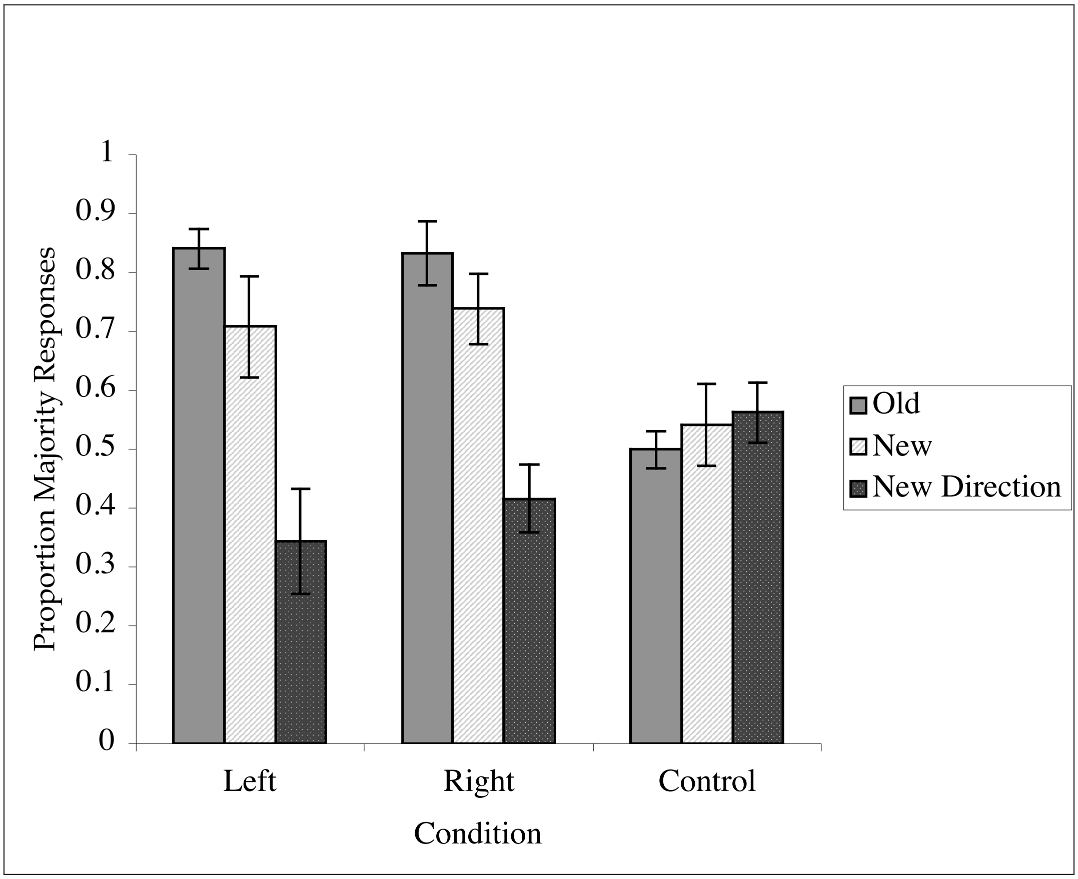
(157) Experiment 1A (Pilot) Results:



(158) Experiment 1 Results:



(159) Experiment 2 Results:



Appendix I: Pilot Stimuli

Training

Maj Rules	Myopic	Ambiguous
bo du tu	bo di ti	bo di ti
bi do ki	bu de ku	bu de ku
bi ne ke	bi ne ke	bi ne ke
do mu ki	do mu ki	do mu ki
do gi be	de gi be	de gi be
di pe be	di pe be	di pe be
go mi to	ge mu to	ge mu to
ge gu bi	ge gi bi	ge gi bi
gi te ke	gu te ko	gu te ko
ki bi pi	ki bi pi	ki bi pi
ki ni tu	ki ni ti	ki ni ti
ku mo te	ki me to	ku mo te
mo nu ko	mo ni ko	mo ni ko
me bi di	me bi di	me bi di
mi ko to	mi ko to	mi ko to
no bo gu	no bo gi	no bo gu
no pi be	ne pi be	ne pi be
ni ti pi	ni ti pi	ni ti pi
po de mi	po de mi	po de mu
pu ku bo	pi ku be	pi ku bo
pi to ne	pi te ne	pi te ne
te ge ni	te ge ni	te ge ni
tu ko pe	ti ke po	tu ko pe
ti pi nu	ti pi ni	ti pi ni

Test Stimuli

Ambiguous		Majority Rules		Myopic	
bekotu	Old	bineke	Old	bineke	Old
bineke	Old	bitoke	UnRound	bitoke	Unround
budeku	Old	budeku	Old	budeku	Old
dipebe	Old	dipebe	Old	dipebe	Old
kebipi	Old	kebipi	Old	kebipi	Old
kimeto	Old	kinope	UnRound	kimote	Old
mebedi	Old	mebedi	Old	mebedi	Old
mikoto	Old	mobenu	Round	mobenu	Round
nitipi	Old	nitipi	Old	nitipi	Old
podemi	Old	pitobu	Round	pimute	Unround
tegeni	Old	tegeni	Old	tegeni	Old
tudupi	Old	tukepo	Old	tudipu	Round
boditu	Round	boketu	Round	boketu	Round

bupidu	Round	bupidu	Round	bupidu	Round
donibo	Round	donibo	Round	donibo	Round
gobipu	Round	gobipu	Round	gobipu	Round
gunito	Round	gunito	Round	gunito	Round
kumeto	Round	kumeto	Old	kubenu	Round
mobenu	Round	muketo	Old	muketo	Old
mukibo	Round	mukibo	Round	mukibo	Round
nopeko	Round	nopeko	Round	nopeko	Round
podobe	Round	podebo	Round	podebo	Round
putebu	Round	podemu	Old	putebu	Round
tudipu	Round	tudipu	Round	timune	Unround
bitoke	Unround	bodutu	Old	boditu	Old
demote	Unround	demote	UnRound	demote	Unround
dikogi	Unround	dikegu	UnRound	dikogi	Unround
gedomi	Unround	gedomi	UnRound	gedomi	Unround
kegube	Unround	kegube	UnRound	kegube	Unround
kinope	Unround	kubenu	Round	kinope	Unround
metuki	Unround	metuki	UnRound	metuki	Unround
negoti	Unround	negoti	UnRound	negoti	Unround
nipuki	Unround	nipuki	UnRound	nipuki	Unround
pimute	Unround	pimute	UnRound	pedomi	Old
teguke	Unround	teguke	UnRound	teguke	Unround
timune	Unround	timune	UnRound	tikope	Old

Appendix II: Experiment 1 Stimuli

Spread Left-Training	Spread Right-Training
bedutu	boduti
bidoku	bonogi
denubo	budoki
dogibe	degibo
domete	demiku
gebupu	dupobe
ginuto	gepibu
mogite	giteko
guteke	gopubi
kebupu	kimeto
kogibe	kinitu
bunepe	kobupi
kuniti	pukope
mebonu	megito
motiki	mobodi
nebogu	monuke
nepoko	nebegu
nutipi	nitipu
pitobu	nodube
pumite	piketo
putene	pitono
tegonu	tikepo
tigunu	togoni
tumine	tuguni

Test Items

Old	New Direction
pumite	pumite
kogibe	kogibe
kunepe	kunepe
motiki	motiki
tumine	tumine
domete	domete
nepoko	nepoko
pitobu	pitobu
ginuto	ginuto
mebonu	mebonu
gebupu	gebupu
denubo	denubo
New	New
nupiki	nipiku
godemi	gedemu
buteke	biteko

dukege	dikego
togike	tegiko
nogeti	negetu
mikobo	mukobe
bedutu	boduti
tidupu	tudupi
pedobo	podobe
kimoto	kumote
bipudu	bupudi
New Direction	Old
gopubi	gopubi
monuke	monuke
mobodi	mobodi
dupobe	dupobe
nopube	nobupe
kukope	kukope
kimeto	kimeto
nebegu	nebegu
gepibu	gepibu
demiku	demiku
miketo	miketo
tikepo	tikepo

Chapter 8: Sour Grapes Spreading (Experiment 3)

Experiments 1-2 support the hypothesis that learners are biased against a majority rules pattern in favor of a directional system. This finding supports the avoidance of such patterns in our theoretical analysis of vowel harmony. Another pathological prediction that our theory of vowel harmony attempts to avoid is sour grapes spreading. As described in Chapter 2, sour grapes harmony patterns occur when a blocker prevents spreading to vowels intervening between the source and the blocker. For the input /+ – –B/ (where 'B' denotes that the final vowel does not undergo harmony), the output [+– –] will be optimal rather than the desired [+ + –]. This type of pathology is produced when the harmony-inducing constraint does not localize the violation of harmony. In both the sour grapes candidate [+ – –] and the spreading candidate [+ + –], there is only one locus of disagreement (where + meets –). However, because the sour grapes candidate incurs no faithfulness violations, it will emerge as optimal.

As discussed in Chapter 7, there is a question of whether unattested patterns like 'majority rules' and 'sour grapes' are principled or accidental. By testing for learning biases for unattested patterns in the artificial grammar learning setting, it is possible to uderstand the nature of restrictions for vowel harmony, particularly unattested patterns. The experiment presented in this chapter is of a different nature than all other experiments presented in the dissertation because the sour grapes pathology requires a non-participating vowel. The learning component of the present experiment must involve a non-participating vowel. It is a question of whether learners will be able to pick up on the nature of the non-participating vowel, particularly whether learners will have a bias in favor of one type of interaction over another. As mentioned in Chapter 4, non-participating vowels can either be transparent or opaque. Transparent vowels allow the spreading feature value to pass through the non-participating vowel, while opaque vowels block the spreading vowel, and initiate a new harmonic domain. The representations required to account for transparent vowels is usally much more complex than the representation of opaque vowels (Bakovic & Wilson, 2000; Booij, 1984; Clements, 1976, 1977; Kiparsky & Pajusalu, 2003; Kramer, 2002; O'Keefe, 2007; Smolensky, 2006). For example, in Bakovic and Wilson's (2000) analysis of vowel harmony in Optimalty Theory, opaque vowels are predicted without any addition to standard OT, but transparent vowels require the extra machinery of targeted constraints. However, in Turbid Spreading, there is no representational complexity for transparent vowels, as the complexity is pre-built into the system in the intermediate, turbid layer of representation where transparency can apply or not at no cost to the system. If the representational complexity found in previous analyses of vowel harmony is correct, then it is possible that this will emerge in learning biases such that transparent non-participating vowels are more difficult to learn than opaque transparent vowels. While the experiment presented in this chapter is primarily concerned with a sour-grapes representation, it will also address the question of whether there are learning biases that favor opaque vowels (compared to transparent vowels), by dividing the experimental training conditions into two types: transparent and opaque. Because the experiments are testing for learning biases, both conditions will be ambiguous for a sour-grapes spreading rule and a directional spreading rule such that all instances of non-participating vowels will not include any other potential undergoers. Critical test items disambiguate between sour grapes and directional spreading by including potential undergoers before the non-participating vowel (e.g., [pukigɛk]).

Experiment 3: Sour-Grapes Spreading

Experiment 3 tests for learners ability to (i) learn about the behavior of non-participating vowels in vowel harmony and (ii) infer that the existence of a non-participating vowel will infer no spreading at all (i.e., sour-grapes spreading). Participants are trained on a back/round harmony rule with either a transparent vowel or an opaque vowel and tested on their learning of the pattern as well as their inferences about sour-grapes spreading.

Method

Participants

All participants were adult native English speakers with no knowledge of a vowel harmony language. Thirty-seven Johns Hopkins undergraduate students participated for extra course credit. Participants were randomly assigned to one of three training groups: a Control Condition containing mixed harmony stems, a Transparency Condition and an Opacity Condition. Final analyses included 12 participants in each of four groups. All participants were screened based on a perceptual (AXB) task. Those participants scoring less than 75 percent on this task were removed from the study. This occurred for 1 participant. The data for 3 participants were dropped due to experimenter error. The data for 1 participant was dropped due to program error.

Design

Participants in the critical training conditions were presented with pairs of items that conformed to a round/back vowel harmony process. The first item in each pair was a stem item of the form CVCVC (e.g., [gipek]) and the second item contained a suffixed form with either [-e] (following front, unrounded vowels) or [-o] (following back, round vowels) (e.g., [gipeke]). All consonants were chosen from the set [p, t, k, b, d, g, m, n] and all vowels were chosen from the set [i, e, u, o, ɛ]. The vowels [i, e, u, o] have harmonic counterparts in the inventory but the front vowel [ɛ] has no harmonic counterpart, and must appear in disharmonic contexts. Because [ɛ] does not participate in harmony, the suffix vowel can either be [-e] or [-o] depending on whether [ɛ] is transparent or opaque. In the Opaque condition, the suffix vowel is always [-e] after [ɛ]. In the Transparent condition, the suffix vowel is always [-o], because the first vowel in the stem is always round [o] or [u]. 12 of the stem items contained the vowels [i, e, u, o], which conformed to the harmony patter, and the other 12 stem items contained the vowel [ɛ], which was either transparent (e.g., [pukɛgo]) or opaque (e.g., [pukɛge]). Examples of training stimuli are provided in the table in (160) below.

(160) Training Stimuli: Experiment 3

Stem	**Transparent**	**Opaque**
[modɛb]	[modɛbo]	[modɛbe]
[pudɛg]	[pudɛgo]	[pudɛge]
[nugɛd]	[nugɛdo]	[nugɛde]
[gobɛk]	[gobɛko]	[gobɛke]
[gitek]	[giteke]	[giteke]
[kukop]	[kukopo]	[kukopo]
[monuk]	[monuko]	[monuko]
[dupob]	[dupobo]	[dupobo]

Following training, participants were given a forced-choice task. In this task participants were presented with two items, one harmonic and one disharmonic.

Participants were asked to choose which pair was the one that would fit the language they were trained on. There were four different test conditions, with 12 items in each test conditions. The Old Items were taken directly from the training set: 6 with the non-participating vowel, 6 without. The New Items condition tested for knowledge of the harmony rule without the non-participating vowel, and the New Transparent Items condition tested for knowledge of transparency or opacity of the non-participating vowel. The fourth test item condition was the Sour Grapes condition. In this condition, items contained the non-participating segment [ɛ] appeared as the third segment in the lexical item, with either the first two segments disharmonic or harmonic (e.g., [pukegɛk] vs. [pukogɛk]). If the participants are biased against a sour-grapes harmony rule, they should prefer the harmonic stems over the disharmonic stems. However, if they learned a sour-grapes harmony rule, they should have no preference. Examples of test stimuli are found in the table in (161) below.

(161) Test Stimuli: Experiment 3

Test Condition	Stem
Old	[gitek]
Old	[degib]
Old	[piton]
New	[nupik]
New	[godem]
New	[bipud]
New Transp/Opaque	[tudɛb]
New Transp/Opaque	[kudɛp]
New Transp/Opaque	[gobɛk]
Sour-Grapes	[pudemɛk]
Sour-Grapes	[tugepɛk]
Sour-Grapes	[kupetɛk]

Stimuli

Each form was produced by an adult male speaker of American English who had no explicit knowledge of the experimental design or hypothesis. The speaker was told to produce all stimuli items without reducing vowels, but to place the main stress on the initial syllable. All stimuli was normalized to 70db.

Procedure

Participants were told that they would be listening to words from a language they never heard before, and that their task was to listen to the way the novel language sounded, but that they need not try and memorize the forms. The training consisted of 24 pairs of item repeated five times each. The first element of each pair was a stem item followed by its harmonic suffixed form (e.g., [pidig, pidege]). The training was followed by a forced-choice test with 48 items. This was followed by a perception task of English vowel contrasts.

Results

Proportion harmonic responses were recorded for each condition: Old, New, New-Transparent, and Sour Grapes for each condition: Control, Opaque and Transparent. A 2 (Training Condition) by 4 (Test Condition) compared harmonic responses between the Control condition and each of the Transparent and Opaque conditions separately.

Results for the ANOVA comparing the Control condition to the Transparent Condition revealed no effect of Training (0.52 vs. 0.57, CI= 0.0.09; $F(1, 22) = 1.65$, $p > 0.05$), an effect of Test Item ($F(3,66) = 3.56$, $p < 0.05$), and no interaction ($F(3, 66) < 1$). Results for the ANOVA comparing the Control Condition to the Opaque Condition revealed no effect of Training (0.52 vs. 0. 54, CI = 0.05; $F(1, 22) < 1$), no effect of Test

Item ($F(3,66) = 2.35$, $p > 0.05$), and no interaction ($F(3, 66) < 1$). These results suggest that neither the Opaque or the Transparent Conditions were able to learn the vowel harmony rule.

We performed additional t-tests comparing each of the Test Conditions to the Control for both the Transparent and Opaque Conditions. We found no effect of training for any training condition on any test condition, suggesting no effect of training across all conditions. There was no difference between the Transparent and Control conditions for Old Items ($t(22) = 1.43$, $p > 0.05$), New Items ($t(22) < 1$), New Transparent Items ($t(22) = 1.09$, $p > 0.05$) or Sour Grapes Items ($t(22) < 1$). There was also no difference between the Opaque and Control conditions for Old Items ($t(22) < 1$), New Items ($t(22) < 1$), New Transparent Items ($t(22) < 1$) or Sour Grapes Items ($t(22) = 1.04$, $p > 0.05$). These results suggest that there was no significant effect of learning for any test condition.

Discussion

Participants in Experiment 3 unable to learn harmony patterns that contain a non-participating vowel. This made it impossible to address the question of sour-grapes spreading in this experiment because learners were unable to show any evidence of learning for the pattern that they were trained on.

There are several possible reasons why participants showed no evidence of learning in the present experiment. One explanation is that learners are biased against non-participating vowels, both transparent or opaque, and exposure to a non-participating vowel may have made it more difficult to learn the overall harmony pattern. Another possibility is that the training set did not have enough training examples or exposure to both the harmony pattern and the disharmony pattern. For example, this experiment has

24 items, 12 with the disharmonic, 12 without, and each item was repeated 5 times. Each participant only received 60 items of harmony and 60 items with disharmony, whereas previous experiments exposed participants to 120 harmonic items. Increasing the number of items in the training set or increasing the number of repetitions for the items in the training set may increase performance on this task. Another possibility is that the 48-items test phase induced un-learning of the harmonic pattern. Other experiments only included 36 items in the test phase. Because each test item contains a harmonic and a disharmonic form, it may be that the more a learner is exposed to test items with disharmonic forms, the more likely they are to unlearn the pattern they were exposed to. While 36 items in the test set does not cause such un-learning, it may be that a 48-item task will cause un-learning. Howeer, there is little to expect this, as I compared the proportion of harmonic responses in the first half of the experiment to the proportion of harmonic responses in the second half of the test phase. There was no significant difference in the Transparent condition (0.59 vs. 0.55 ($t(11) < 1$), the Opaque condition (0.51 vs. 0.51; $t(11) < 1$) or the Control Condition (0.54 vs. 0.49 $t(11) < 1$), though the numerical difference is in the correct direction for the Transparent and the Control conditions.

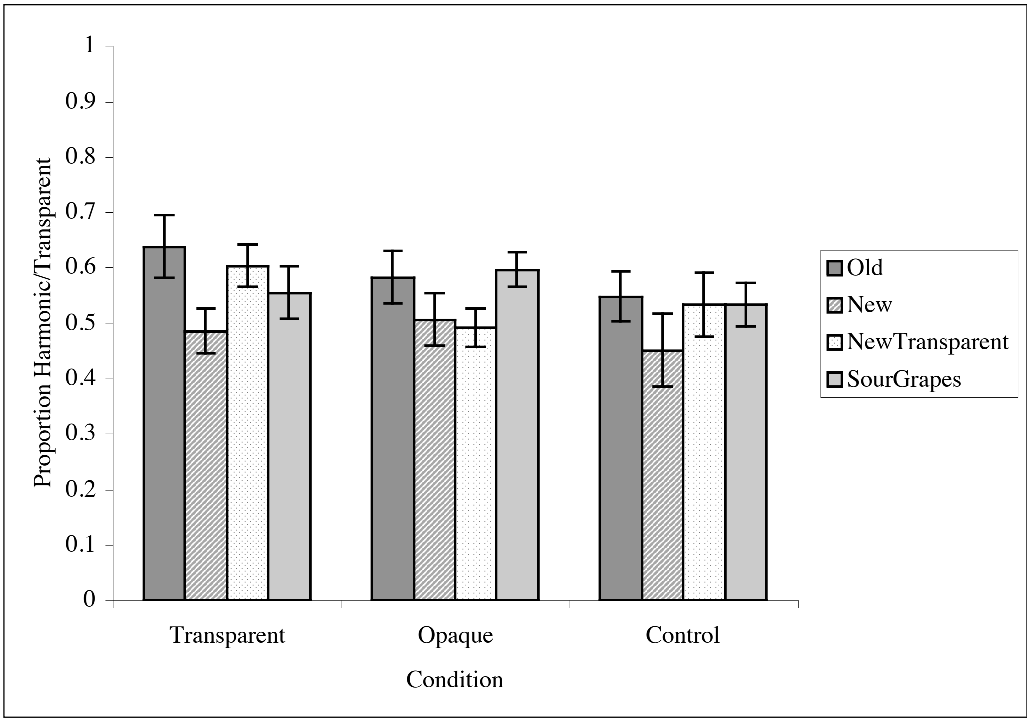
Another potential confound in this experiment is that because half of the items in the training items contained a disharmonic vowel, a disproportionate number of items ended in [e] in the opaque condition and [o] in the transparent condition. If a very large percentage of the suffixed items ended in the same vowel, then it may have been difficult for learners to infer the alternation of the suffix vowel. Future experiments will control for the percentage of items ending in [e] and [o] to ensure that participants are able to infer the harmony alternation from the data.

Future experiments will attempt to address these potential issues with the present experiment, with the hope that we can induce learning of a harmony pattern with transparent and opaque vowels using the artificial grammar learning paradigm.

CONCLUSION

The present experiment tested whether learners have a bias towards a 'sour-grapes' pattern of spreading in which the presence of a vowel that does not undergo harmony will induce disharmony throughout the lexical item. Because participant were unable to learn a harmony pattern that contained non-participating vowels, we were unable to assess whether there is any bias for or against 'sour-grapes' spreading. There may, however, be a bias against non-participating vowels in harmony that future research will investigate.

(162) Experiment 3 (Sour Grapes) Results:



Appendix I: Experiment 3 Stimuli

Training Items

bupɛt
gupɛk
dotɛb
tukɛd
pokɛg
tomɛn
konɛp
kunɛm
modɛb
pudɛg
nugɛd
gobɛk
gitek
kukop
gemit
tikep
monuk
dupob
miket
kimet
degib
nopub
budok

Test Items

Old	gitek
Old	kukop
Old	gemit
Old	tikep
Old	monuk
Old	dupob
Old	miket
Old	kimet
Old	degib
Old	pitono
Old	nopub
Old	budok
New	nupiki
New	godemi
New	buteke
New	dukege
New	togike
New	nogeti
New	mikobo
New	bedutu
New	tidupu
New	pedobo
New	kimoto
New	bipudu
New Transp/Opaque	tudɛbi
New Transp/Opaque	kudɛpe
New Transp/Opaque	todɛpi
New Transp/Opaque	kudɛke
New Transp/Opaque	pomɛki
New Transp/Opaque	togɛke
New Transp/Opaque	kogɛme
New Transp/Opaque	kupɛgi
New Transp/Opaque	mokɛni
New Transp/Opaque	pukɛne
New Transp/Opaque	nutɛmi
New Transp/Opaque	gobɛke
Sour-Grapes	pudemɛ
Sour-Grapes	tugepɛ
Sour-Grapes	kupetɛ

Sour-Grapes	bonekɛ
Sour-Grapes	dogemɛ
Sour-Grapes	gotebɛ
Sour-Grapes	motidɛ
Sour-Grapes	nogimɛ
Sour-Grapes	pokinɛ
Sour-Grapes	gunipɛ
Sour-Grapes	mubinɛ
Sour-Grapes	dutigɛ

Chapter 9: Feature-Based Representations (Experiments 4-6)

One of the major goals of phonological theory is to uncover the precise nature of phonological representations, and how such representations are acquired. The primary source of evidence for theories of phonological representation has come from studies of phonemic distributions and phonological alternations. The representations that linguists have posited, such as autosegmental feature geometries (Clements, 1985; Goldsmith, 1975), and the hierarchical structure of syllables (Hayes, 1995) serve to explain patterns of phonological data. As Anderson (1981) has argued, abstract phonological features are necessary to capture even the most phonetically natural processes. While the bulk of phonological theory has assumed that mental representations of phonemic segments consist of sets of distinctive features, there has been some debate regarding the nature of these features. For example, the traditional generative approach to phonology cannot handle 'performance' factors such as frequency and fine-grained phonetic details. This concern has lead some phonologists to question the existence of abstract elements like features altogether, in favor of an exemplar based approach to language in which abstract phonological processes are no represented. Rather, the speaker only needs to store similarities and frequencies of phonetically detailed memory traces of segments (categories), morphemes and lexical items (Johnson, 1997, 2005; Kirchner, 2004; Nosofsky, 1986, 1988; Pierrehumbert, 2000, 2003; Port & Leary, 2005). These proposals raise the prospect that feature-based representations can be done away with altogether.

Feature-based theories and theories of phonological representations that exclude features make a number of contrasting predictions that are in need of examination. Specifically, feature-based theories posit that abstract sub-segmental representations must be available to the language learner. Investigating the type of generalization that language learners can make provides insight into this availability. One promising approach to testing the predictions made by these contrasting theories is the artificial language learning paradigm.

The experiments presented here address this question using the poverty of the stimulus method for artificial language learning (Wilson, 2006). This method involves a test phase that includes items heard at training, novel items (that include all the same segments heard in training) and items containing novel segments (not heard during training). If learners make use of feature-based representations during learning, then they should generalize to novel segments; if they learn at the segment level, they should not generalize to novel segment types. The experiments use a morphophonological alternation related to vowel harmony to test these different proposals.

Vowel harmony is a good phonological process for testing the level of generalization to novel segments because this process can involve all major distinctive features: round, back, high and tense (van der Hulst & van de Weijer, 1995). If learners are able to use natural classes in a vowel harmony situation, then it is likely that they will use natural classes in other rules that they learn, supporting theories of phonological processing that have sub-segmental structure (see Goldrick (2002) for an overview of theories of phonological processing).

To make the issue more concrete, consider a hypothetical language with front/back vowel harmony in which front vowels [i, e, æ] trigger the front vowel suffix [-mi] (e.g., [bæge-mi]; [nibe-mi]), and back vowels [u, o, a] trigger the back vowel suffix [-mu] (e.g., [dopa-mu]; [bano-mu]). If the learner is exposed only to non-low vowels [i, e, u, o], different theories of learning make varying predictions as to whether the learner will treat low vowels, which they have never heard before, as harmony triggers (i.e. prefer [-mi] for [bægæ], but [-mu] for [bano]). Each learning hypothesis predicts a different approach to rule formulation when the learning data is incomplete in this way.

Hypothesis 1 (163) posits segmental learning, while Hypothesis 2 (164) posits sub-segmental learning. In segmental learning, the highest level of abstraction is the segment (Hypothesis 1). The learner is unable to make learning hypotheses beyond the segment level. The sub-segmental learning hypothesis assumes that learners make use of representations that are below the segment level, such as features and natural classes. This implies that learners should be able to generalize to novel stimuli beyond the segment level.

(163) *Hypothesis 1: Segment-Based Learning*: Learners form their rules based entirely on the behavior of specific, familiar segments. This allows them to formulate segment-based generalizations, but they should not extend their generalization to novel segments.

Harmony Rule: V → [i] / {i, e} C ___

V → [u] / {u, o} C ___

(164) *Hypothesis 2: Feature-Based Learning Hypothesis:* Learners posit the most general pattern that fits the data. As long as novel segments fit into this highly general rule, the learner will generalize to novel segments.

Harmony Rule: V → [BACK] / [BACK] C ___
A vowel becomes back following a back vowel

Because vowel harmony is not a phonological process in English (and does not appear to be used as a phonetic cue for speech segmentation (Vroomen et al., 1998)), it is possible to use vowel harmony to teach adults a novel phonological process. Vowel harmony is also an ideal way to test the hypotheses posed above because as we have emphasized, harmony is based on natural classes, and therefore allows us to test the type of generalization that learners make when exposed to vowel harmony with an incomplete data set.

These two hypotheses make different predictions about when a learner will generalize to segments that they have never heard before. The segment-based hypothesis predicts no generalization beyond the actual segments presented in the training stimuli, but the feature-based hypothesis predicts generalization for any novel segment. Intuitively, each learning hypothesis has its appeal. The segment-based hypothesis requires no abstraction or higher-level generalization, simply memorization of the segments that trigger each suffix. The general feature-based learning hypothesis is attractive because it favors the simplest rule in formal terms.

By manipulating the type of segments/feature-combinations that are withheld during the learning phase, it will be possible to differentiate between these hypotheses.

Previous Studies

While there is indirect evidence that learners generalize over features (Goldrick, 2004; Guest et al., 2000; Kingston, 2003; Pycha et al., 2003; Seidl & Buckley, 2005; Wilson, 2003b, 2006), there is also evidence to support the segment-based learning hypothesis (Chambers, Onishi, & Fisher, 2003; Newport & Aslin, 2004; Peperkamp, Le Calvez, Nadal, & Dupoux, 2006; Peperkamp, Skoruppa, & Dupoux, 2006). Additionally, none of the past studies have directly addressed the question of the existence of feature-based learning, and how such feature-based learning might take place.

For example, Seidl and Buckley's (2005) artificial grammar learning experiment made use of novel segments in the test phase, but these test items were not scored independently of trained-on segments. In their experiment, Seidl and Buckley used the

Head Turn Preference Procedure (Jusczyk & Aslin, 1995; Kemler Nelson et al., 1989) to test 9 month-olds on their learning of a phonological rule whereby only a particular natural class could occur between vowels (e.g., fricatives ([f, s] etc.) but not stops ([p, g], etc.); [ifi] but not *[igi]). Infants were able to differentiate between novel grammatical items and novel ungrammatical items in the test phase, indicating that the infants were able to learn this phonological process. However, it is unclear whether infants in this experiment actually generalized at feature level because the test items with novel segments were not scored independently of other items (the stimuli were scored in blocks of three lexical items (e.g., [ifi], [eve], [esi]), only one of which contained novel segments ([eve])).

In Goldrick's (2004) study, participants were trained using novel phonotactic constraints. In this experiment, coronals ([t, d, n]) were biased towards coda (syllable-final) position such that these sounds occurred more often than other sounds in syllable-final position. (e.g., the sequence [hɛn fɛt mɛd nɛk] contains three coronal codas and one non-coronal coda). To test whether participants had learned this coronal bias, participants were asked to pronounce similar nonsense sequence aloud, as quickly as possible, in order to induce speech errors. These speech errors were measured in order to test learning of the phonotactic constraints. Participants' error patterns conformed to the coronals in coda bias, even for coronals not found in the training set, suggesting feature-based learning of the phonotactic constraint. However, when participants were trained on the same constraint with the phonological feature dorsal ([k, g, ŋ]), there was no generalization to novel segments, indicating that feature-based generalization has its limitations.

This poses the possibility that learners may make use of multiple strategies in forming hypotheses about phonological processes. Wilson's (2006) study found differences in generalization for different segments. His experiment tested for biases in velar palatalization (e.g., /kim/ ⇒ [tʃim]). Cross-linguistically, palatalization before mid vowels entails palatalization before high vowels, but not vice versa. In conforming to this pattern, speakers who were exposed to mid vowels generalized to high vowels, but participants who were trained on high vowels did not generalize to mid vowels. Further, neither the segment-based nor the feature-based learning hypotheses predict this pattern of generalization, suggesting the need for a supplement to the above hypotheses. The above hypotheses assume learning in a vacuum; that no other knowledge should influence the type of rule that the learner posits. However, the adult learner is equipped with the ability to make use of the perceptual, articulatory and formal aspects of grammar gleaned from experience with his or her native language. One possibility is that learners make use of these principles when they encounter novel phonological patterns (Dupoux, Kakehi, Hirose, Pallier, & Mehler, 1999; Peperkamp & Dupoux, 2002). If learners make use of prior knowledge in positing grammatical processes, it is possible that the pattern they infer from the data may include or exclude particular segments depending on whether one such segment has the acoustic or grammatical properties that will make it a good participator in the pattern. We will leave this as an open possibility for the time being, and return to this in the Discussion section.

The Experiments

In Experiment 4, front/back harmony is instantiated in the form of a morphophonological suffix alternation (i.e., [-mi]/[-mu]). For each two-syllable stem, both vowels were drawn either from a front vowel set [i, e, æ] or from a back vowel set [u, o, a]. The suffix alternates to agree with the natural class of the stem vowel. For example, the stem [bada] is suffixed as [badamu] and not *[badami]. Using suffixed forms as training provides learners with evidence for a front/back harmony rule. Learners (in one condition) are exposed to stimuli consisting of high and low vowels [i, u, æ, a] but not mid vowels [e, o]; in another condition, learners are exposed to mid [e, o] and high vowel stimuli [i, u] only. If learning extends beyond the specific lexical examples in the training set, then after hearing [badamu], learners should also treat new words with old vowels such as [kanamu] as grammatical. If the learner is also able to extend the pattern to novel segments, this will indicate that feature-based representations are used in learning.

Previewing the results of Experiment 4, participants extend the harmony pattern to mid vowels but not low vowels, partially supporting the feature-based hypothesis. Experiment 5 tests two possible explanations for this result: interpolation over extrapolation versus suffix-based alternations. The language in Experiment 5 involves a back harmony alternation only by using low vowel suffixes [-mak]/[-mæk], which only alternate in the back feature to test generalization to high and mid vowels. Participants generalize to both high and mid vowels, supporting the suffixed-based hypothesis and ruling out and interpolation-only learning strategy.

Experiment 6 tests for further generalization to novel target segments. In this experiment, we test for generalization to novel suffix vowels. If learners form general phonological rules, the learner should be able to form rules that are general enough to apply to both novel triggers (stem vowels), as well as novel targets (suffix vowels). Our results indicate that learners are able to learn rules that are abstract enough to apply to novel suffixes.

EXPERIMENT 4

As mentioned above, Experiment 4 exposes learners to a harmony pattern with alternations in the suffix from [-mi] to [-mu]. Each of the different hypotheses presented above make different predictions about the type of process that learners will infer based on the segments that trigger the alternation between [-mi] and [-mu]. The segment-based hypothesis predicts that learners will extend the harmony pattern to all segments heard in training, but not to novel segments. The feature-based learning hypothesis predicts that learners will extend the harmony pattern to any novel segment that conforms to the generalization over front versus back vowels.

Method

Participants

All participants were adult native English speakers with no prior experience with a vowel harmony language. Fifty-six Johns Hopkins undergraduate students participated for extra course credit.

Design

There were 14 participants in each of three training conditions: a Low Hold-Out condition and a Mid Hold-Out condition and two Control conditions, one matched for each of the Low Hold-Out (Control-Low) and the Mid Hold-Out (Control-Mid).

The experiment consisted of a training phase followed immediately by a forced-choice test. All phases of the experiment were presented using PsyScopeX (Cohen et al., 1993). For the critical experimental conditions (Low and Mid Hold-Out conditions), the training consisted of 24 pairs of stems and stem plus suffix items (e.g., [bada, badamu]). The Control condition (mixed harmony stems) had 48 stems. This was double the number of stems in the other training conditions so that Control training could consist of identical stems in the Mid and Low Hold-Out conditions, as well as disharmonic stems. The Control-Mid condition heard harmonic stems that matched the Mid Hold-Out condition and the Control-Low condition heard stems that matched the Low Hold-Out condition. Because the Control participants did not hear suffixed forms, all participants heard the same number of words in the training phase.

Participants in the Low and Mid Hold-Out conditions heard a stem (e.g., [bidi]) followed its suffixed form ([bidimi]) after a 500 ms pause. Each participant heard each pair five times, in one of two randomized orders. The test consisted of a forced-choice task with 36 forced-choice pairs, in a randomized order counterbalanced to control for order effects. The 36 items were divided into 4 randomized blocks of 8. Half of the participants heard blocks 1 and 2 first, and blocks 2 and 3 second. The other half of the participants heard blocks 4 and 2 first, and 1 and 3 second.

Each pair consisted of a suffixed item, identical in all respects except for the suffix vowel: either [-mi] or [-mu] (e.g., [bidimi bidimu]). Each test item was in one of three conditions: Old Stems, New Stems, or New Vowel. The Old Stems condition contained items that appeared in training. New Stems items did not appear in training, but were drawn from the same vowel and consonant inventory as the training items. New

Vowel test items consisted of vowels that did not appear in the training inventory, but consonants that did appear in the training inventory.

Because the experiments are testing the nature of learning in an artificial grammar setting, it is necessary to ensure that the effects that we find are actually due to learning, rather than a prior bias, or bias in selecting particular items (Redington & Chater, 1996). We created Control conditions to ensure that all effects were due to specific learning strategies. One option for a Control condition is to give these participants no training data at all, and simply give test items to these participants. However, we do not feel that this is an adequate Control for the present experiment for two main reasons. First, the participants in this task would require very different instructions. As they would have no training to base their responses, they would have to be given some background, which would result in very different test instructions for these participants, which may influence the results. Second, having no basis for response, participants may use a strategy that is entirely different from any strategy that participants in the training conditions might employ.

We feel that the ideal Control condition should be designed to simulate an environment in which there is no basis for inferring a phonological rule from the data. One option for this would be to give participants a mixture of a harmonic and disharmonic alternations, so that half of the training items would have a disharmonic suffix and the other half would have a harmonic suffix. The problem with this approach is that all the stems are bi-syllabic and harmonic. If Control participants notice the harmony in stems, they may be influenced to learn the harmonic pattern they are exposed to and ignore the disharmonic pattern. Further, the learners in the Control condition may be biased to learn a harmony pattern over a disharmony patter (or vice versa) and remember either the harmonic or disharmonic pattern better. This type of training would not simulate a condition in which no learning occurred. Our solution was to expose Control participants to a mixture of both harmonic and disharmonic stems. The harmonic stems are identical to the harmonic stems in the other training conditions. The presence of disharmonic stems ensures that the learner finds no harmony or disharmony pattern in the training set, but is given equivalent exposure to the language (an identical number of lexical items in the training set). While it is an empirical question as to whether it is necessary to expose learners to morphophonological alternations to learn the vowel harmony pattern, exposing Control participants only to stems should give minimal information as to the relationship between the stem vowels and the suffix vowel. Only exposing Control participants to stems creates the greatest chance for Control participants to express their pre-existing biases for harmonic or disharmonic forms. We created two Control conditions, each matched for the other training conditions: the Control-Mid participants heard stimuli that contained the same vowels as items in the Mid Hold-Out condition ([i, u, æ, a]), and the Control-Low heard stimuli that corresponded to items in the Low Hold-Out condition ([i, u, e, o]). Test items were also counterbalanced to match the Mid Hold-Out or the Low Hold-Out condition depending on the vowels heard in their training stimuli. All Old Stem items appeared as harmonic stems in the Control conditions.

Finally, no explicit feedback was given to participant following training or test. While any artificial language task contains some level of arbitrariness, leaving out explicit feedback makes the learning as close to a natural setting as possible and helps to minimize the use of explicit learning strategies.

<u>Materials</u>

All stimuli were recorded in a sound proof booth at 22,000kHz by a male speaker of American English with basic phonetic training (had completed a graduate-level phonetics course). While the speaker had no knowledge of the specifics of the experimental design, he was aware that the items would be used in an artificial language learning task. All stimuli were phonetically transcribed, and presented to the speaker in written format. The speaker was instructed to produce all vowels as clearly and accurately as possible, even in unstressed positions. Stress was produced on the first syllable.

All sound editing was done using Praat (Boersma & Weenink, 2005). All stimuli contained the same consonant inventory: [p, b, t, d, k, g, m, n]. The inventory for vowels in the training for Control and Mid Hold-Out condition consisted of [i, u, æ, a]. The training vowel inventory for the Low Hold-Out condition consisted of [i, u, e, o]. The vowel inventory for the test conditions consisted of all six vowels: [i, u, e, o, æ, a]. Suffixed forms consisted of the stem plus either [-mi] or [-mu] as the suffix. The suffix [-mi] is harmonic with front vowels [i, e, æ] while the suffix [-mu] is harmonic with back vowels [u, o, a].

Suffixed stimuli were created by splicing a pseudo-suffixed form with a central vowel ([ə] (stem [-mə]; e.g. [badamə])) and a spliced portion of a suffixed form of a central stem [-mi] or [-mu]. For example, the form [dekemi] was created by crossing the stem portion of [**deke**mə] with the suffix portion of [dəkə**mi**]. Therefore, the stimuli in the test conditions, which contained both harmonic and disharmonic forms, had identical stem portions, and differed only by the suffix. This ensured that selection of the suffixed form was due to the suffix itself and not an idiosyncrasy in the stem. Two native speakers of American English (with no knowledge of the experimental design) rated the quality of the splicing for all stimuli. Stimuli with low ratings were either re-recorded or re-spliced. All splicing was performed at zero crossings. The F2 for the final stem vowel was also measured to ensure that the front/back vowel dimension was acoustically present.

The training stimuli were counterbalanced to contain all possible combinations of vowel sounds, both with equal numbers of identical (repeated) and non-identical (non-repeated) pairs of vowels across all conditions. For the four vowels in the training set, the 8 possible vowel pairs were repeated three times each for a total of 24 training items ([i, i], [i, æ], [æ, i], [æ, æ], [u, a], [a, a], [u, u], [a, u] in the Mid Hold-Out Condition). Consonantal skeletons were made for each of the eight vowel pair three times for a total of 24 training words. Consonant skeletons were constructed so that each of the eight consonants ([p, b, t, d, k, g, m, n]) occurred in word initial position three times and word-medial position three times. Vowel pairs were assigned to consonant skeletons semi-randomly with the condition that any word too closely resembling an English word was intentionally avoided (the final profile of the stimuli was counterbalanced to appropriately contain equal numbers of consonant pairs and a consistent number of vowel pairs). Consonant skeletons were created in the same manner as the training for new and new vowel test conditions. Stimuli lists are provided in Appendix I, as well as examples in the table in (170).

Procedure

All participants were given written and verbal instructions. They were told that they would be listening to a language they had never heard before, and that they would later be asked about the language, but they need not try to memorize any forms they heard. No information about vowel harmony or about the morphology of the language was given. No semantics accompanied the sound pairs. Participants heard all stimuli over headphones. Training then consisted of the 24 stem and stem+suffix pairs (e.g., [bidi, bidimi]) repeated 5 times each. When training was complete, a new set of instructions appeared on the monitor. Participants were told that they would hear two words, one of which was from the language they just heard, and their task was to identify which word belonged to the language. If the first item of the pair belonged to the language, they must push the 'a' key on the keyboard; if the second item belonged to the language, they must press the 'l' key on the keyboard. Participants were told to respond as quickly and accurately as possible, and to make their responses after hearing both items. Participants were given a debriefing statement upon completion of the experiment (which took approximately 15 minutes). While we did not probe participants as to whether they noticed the purpose of the experiment or obtained explicit knowledge of the phonological process, pilot subjects reported that they were unaware of the purpose of the experiment, and had no explicit knowledge of the phonological rule.

Results

Percent of harmonic responses were recorded for each subject for each of the training conditions. The mean responses for each test condition are presented in the figure in (165). All conditions involved between-item comparisons. Means and 95 percent confidence intervals (*CI*; Mason & Loftus, 2003) for each condition are provided in the analysis.

The feature-based learning hypotheses predicted generalization to mid vowels in the Mid Hold-Out condition. This generalization was tested first by comparing overall performance in the Mid Hold-Out Condition to the Control Condition, to ensure that there was an overall learning of the harmony pattern. This overall learning was assessed using a two-factor analysis of variance (ANOVA) with alpha set at $p = 0.05$. The between-subjects factor was Training (Control and Mid Hold-Out). Test Items (Old Stems, New Stems, New Vowel) was a within-subjects factor nested under the between-subjects factor Training.

For the ANOVA comparing the Control-Mid condition to the Mid Hold-Out condition, there was a significant effect of Training ($F(1, 26) = 36.83$, $p < .001$); participants in the Mid Hold-Out condition were more likely to make harmonic responses than Controls (mean = 0.64 vs. 0.54, $CI = \pm 0.074$), providing evidence of learning. There was no effect of Test Item ($F(2, 52) = 2.11$, $p > 0.05$) and no interaction ($F(2, 52) = 1.73$, $p > .05$).

To assess generalization to novel mid vowels, a t-test was performed between the New Vowel in the experimental condition and the New Vowel condition of the Control-Mid condition. There was a significant difference between New Vowel test items in the Mid Hold-Out condition and the Controls (0.73 vs. 0.54, $CI = \pm 0.10$; $t(26)= 288$, $p < 0.05$) suggesting generalization to novel mid vowels. To assess the robustness of generalization to novel mid vowels, a planned contrast comparing the New Vowel test items to the New Stems test items was performed. If participants are as likely to harmonize to new vowels as to new stems, then there is a good reason to believe that participants generalized to novel vowels. Harmonic responses to New Vowel items was significantly greater than harmonic items for New Stems test items (0.73 vs. 0.61, *CI* = ± 0.073; $F(1, 13) = 6.67$, $p < 0.05$), suggesting robust generalization to novel mid vowels.

The feature-based learning hypothesis also predicted generalization to novel low vowels. To assess overall learning, an ANOVA was performed comparing the Low Hold-Out Condition to the Control-Low Condition (mean = 0.73 vs. 0.45, *CI* = ± 0.049). There was an effect for Training ($F(1, 26) = 67.54$, $p < 0.001$); participants in the Low Hold-Out condition were more likely to make harmonic responses than participants in the Control-Low condition, providing evidence of learning. There was a significant effect of Test Item ($F(2, 52) = 13.99$, $p < 0.001$), and a significant interaction of the factors ($F(2, 52) = 13.11$, $p < 0.001$).

To assess the nature of the interaction found in the ANOVA comparing the Control Condition to the Low Hold-Out condition, we performed a post hoc Tukey test. We compared the Control condition to the Low Hold-Out condition for all three test conditions: Old Stems, New Stems and New Vowel. The comparisons for New Stems and Old Stems were both significant ($p < .05$), but the comparison between Control New Vowel test items and New Vowel test items for the Low Hold-Out condition was not ($p > .05$).

We probed for generalization to novel low vowels with a t-test comparing the New Vowel condition in the Low Hold-Out condition to the New Vowel condition in the Control condition (mean = 0.53 vs. 0.46, *CI* = ±0.069). We found no effect of training ($F(26)=1.74$, $p > 0.05$), suggesting no generalization to Low Vowels.

To ensure that there was no difference between Control participants that were given items analogous to the Low Hold-Out condition and Control participants that were given items analogous to the Mid Hold-Out condition, we performed a mixed-design ANOVA comparing each type of test item. This was assessed using a two-factor analysis of variance (ANOVA) with alpha set at $p = 0.05$. The between-subjects factor was Training (Control-Mid and Control-Low). Test Items (Old Stems, New Stems, New Vowel) was a within-subjects factor nested under the between-subjects factor Training. There was an effect of Training (mean = 0.54 vs. 0.45, $CI = \pm 0.029$; $F(2, 52) = 4.96$, $p < 0.05$), no effect of Test Item ($F < 1$) and no interaction ($F < 1$). To ensure that biases for novel vowels was the same, we performed a t-test comparing in the New Vowel condition for each of the Control conditions, and found no difference between the conditions ($t(26)=1.71$, $p > 0.05$). The significant effect of Training for the Control conditions is surprising given the outcome of the training for the analogous conditions. However, we suspect that this difference is due to statistical fluctuations from 50% chance: Control-Mid was slightly above chance, while Control-Low was slightly below chance.

Discussion

Based on the fact that Training was significant for both Hold-Out conditions when measured against the Control condition, we can be reasonably certain that participants learned the harmony pattern. The results of this study indicate that participants applied the harmony pattern to novel stem+affix forms, involving familiar vowels only, but only applied the pattern to novel mid vowels. Participants failed to apply the harmony pattern to low vowels, even when they were exposed to low vowels at training. This is supported both by lack of generalization to novel vowels in the Low Hold-Out Condition, and by the fact that participants had fewer harmonic responses to New Stem items ending in low vowels.

These findings suggest that learners are able to generalize at the feature level, but that this generalization is constrained. The fact that participants generalized from high and low vowels to mid vowels but not from high and mid vowels to low vowels supports some kind of sub-segmental representation. However, the fact that participants did not generalize to novel low vowels in the Low Hold-Out condition suggests that there needs to be refinement of the feature-based learning hypothesis. The two most plausible possibilities are: (i) that participants learn at the feature level, but generalize to novel segments based on interpolation and not extrapolation and; (ii) that learners infer novel phonological processes based on the alternating features of the suffix allomorphs.

The interpolation hypothesis is based on the fact that more diverse stimuli produce greater generalization (Hahn, Bailey, & Elvin, 2005). This hypothesis predicts that learners will generalize to novel mid vowels from high and low vowel training stimuli because mid vowels fall within the range of high and low, and will interpolate that mid vowels should undergo the process. However, generalization to low vowels from mid and high examples requires extrapolation. If learners are less likely to extrapolate than interpolate, then they will be less likely to generalize to novel low vowels

The suffix allomorph hypothesis predicts that because the suffix alternation [-mi]/[-mu] is an alternation in rounding as well as backness, and low vowels [a] and [æ] do not contrast in rounding, these low vowels will not participate in the harmony process. Cross-linguistically, low vowels frequently fail to participate in harmony that involves rounding alternations, as in the alternation of [-mi]/[-mu] (Kaun, 1995, 2004). This suggests that there is an aversion to low vowels participating in round harmony. This aversion is based on the fact that low vowels are typically not specified for the feature round. Round harmony is almost always triggered by a specified [+Round] vowel, meaning that in order for vowels to trigger harmony from a stem to a suffix, the vowel must be specified for round, and contain contrasting round features. Because low vowels do not fit this criterion, when low vowels are in the stem, they will fail to trigger harmony.

The suffix allomorph explanation makes a slightly different prediction about the behavior of low vowels than the interpolation explanation. If learners are biased against allowing low vowels to trigger round harmony, then it should be more difficult to generalize to low vowel harmony triggers, for New Stems (in the Mid Hold-Out condition) or New Vowels (in the Low Hold-Out condition). We have already seen that learners fail to generalize to low vowels in the Low Hold-Out condition, and there is some suggestion that learners failed to generalize to low vowels in New Stems in the Mid Hold-Out condition because there were fewer harmonic responses to New Stems than New Vowels in the Mid Hold-Out condition.

To test whether participants in the Mid Hold-Out condition generalized to low vowels in the New Stem condition (Experiment 5), we compared participants' harmonic responses to New Stem items ending in low vowels (mean = 0.49) to new stems with high vowels (mean = 0.70) (illustrated in figure 2), and found significantly higher harmonic responses to high vowel items than low vowel items ($t(13) =$, $p < 0.01$). This suggests that participants in the Mid Hold-Out condition did not generalize to low vowels, even though these items were present in the training set. This supports the suffix allomorph explanation, which predicted that learners would infer a harmony pattern that applied only to vowels that alternate in rounding because the alternation between [-mi] and [-mu] involves a change round features (as well as back features).

In order to completely rule out the interpolation-based hypothesis, we explore learning for a suffix vowel alternation in low vowels, which will be contrastive for only one feature: [BACK]. If learners use interpolation rather than extrapolation, they will generalize to novel mid vowels but not to novel high vowels. However, if learners use a general feature-based learning strategy, they will generalize to novel mid as well as novel high vowels.

Before continuing on, it is important to address the possibility that the Control condition used in Experiment 4 underestimated the learner's bias towards harmony. In our control Condition, participants were exposed equal numbers harmonic and disharmonic stem forms. It is possible that this level of exposure to disharmonic forms may have decreased any initial bias towards harmonic forms. To investigate this possibility, we ran a separate version of our control condition, presented below.

EXPERIMENT 4B

Experiment 4B explores the possibility that exposing control participants to disharmonic forms decreases their initial bias to harmonic forms. In Experiment 4B, we expose participants to single syllable training items.

Method

Participants

All participants were adult native English speakers with no prior experience with a vowel harmony language. Fourteen Johns Hopkins affiliates participated either for extra course credit or monetary compensation ($7).

Design

The procedure for Experiment 4B was identical to Experiment 4 except that participants were trained on single-syllable items. Each item was copied directly from the control condition in Experiment 4.

Materials

All training stimuli were spliced from the training for the Control condition of Experiment 4. Syllables were spliced at the syllable boundary of each of the two-syllable training items from the Control stimuli in Experiment 4 (all at zero-crossings). All test items were identical to those of Experiment 4.

Procedure

All participants were given the same instructions as participants in Experiment 4. However, because training items in this experiment had only one syllable, but test items had three syllables, participants were warned that there might be a difference between training and test items, but that they should do their best on the test despite this difference.

Results

Percent of harmonic responses were recorded for each subject for each of the training conditions. The mean responses for each test condition are presented in the figure in (167) below.

We compared the two control conditions via a two-factor ANOVA. For Control-Mid, there was no effect of Training (0.54 vs. 0.53, *CI* = ± 0.11; F < 1), no effect of Test (F < 1) and no interaction (F < 1). For Control-Low, there was there was no effect of Training (F (1, 26) = 3.09, p > 0.05), no effect of Test (F < 1) and no interaction (0.44 vs. 0.53, *CI* = ± 0.064; F (2, 52) = 1.41, p > 0.05). These results suggest that there was no difference between the Control conditions in Experiment 4 and Experiment 4B.

Participants in the Control 4B condition were also compared to participants in each of the training conditions from Experiment 4 via a separate ANOVA with alpha set at p = 0.05. The between-subjects factor was Training (Control, Mid Hold-Out or Low Hold-Out). Test Items (Old Stems, New Stems, New Vowel) was a within-subjects factor nested under the between-subjects factor Training. All conditions involved between-item comparisons.

For the ANOVA comparing Control4B to the Mid Hold-Out condition of Experiment 4, there was a significant effect of Training (F (1, 26) = 8.91, p < .05); participants in the Mid Hold-Out condition were more likely to make harmonic responses than Controls (mean = 068. vs. 0.53, *CI* = ± 0.077), providing evidence of learning. There was no effect of Test Item (F < 1) but a significant interaction (F(2,52) = 4.19, p < 0.05). These results are identical to those obtained in Experiment 4.

The ANOVA comparing the Control 4B to the Low Hold-Out condition of Experiment 1 (mean = 0.53 vs.0.73, *CI* = ± 0.072) also contained an effect for Training ($F(1, 26) = 16.36$, $p < .001$); participants in the Low Hold-Out condition were more likely to make harmonic responses than Controls, providing evidence of learning. There was a significant effect of Test Item ($F(2, 52) = 15.09$, $p < .001$), and a significant interaction between the factors ($F(2, 52) = 10.51$, $p < .001$) most likely reflecting the poor performance of participants in the Low Hold-Out condition on New Vowel test items. These results are identical to those from the analyses of Experiment 1, based on the original control condition.

For all ANOVA's containing a significant interaction, post hoc Tukey tests were performed. We compared the Control 4B condition to the Hold-Out condition for all three test conditions: Old Stems, New Stems and New Vowel. The comparisons for New Stems and Old Stems were both significant ($p < .05$), but the comparison between Control New Vowel test items and New Vowel test items for the Low Hold-Out condition was not ($p > .05$).

To assess whether there was a difference in the New Vowel test items, a t-test was performed between the New Vowel items in the experimental conditions and the mean of New Vowels in Control 4B. There was a significant difference between New Vowel test items in the Mid Hold-Out condition and the Controls (0.73 vs. 0.51, *CI* = ± 0.078; $t = 3.70$, $p < .01$), but no difference between New Vowel test items in the Low Hold-Out condition and the Controls (0.53 vs. 0.51, *CI* = ± 0.073; $t < 1$), indicating that there was no generalization to low vowels. These results are identical to those found with the alternative Control condition.

Discussion

The results of Experiment 4B provide evidence that the Control conditions used in our experiments are sound. We obtain the same results from Experiment 4 as from Experiment 4B. The fact that there is no significant difference between Control 4A and Control 4B provides evidence that exposing participants to disharmonic stems in the control condition does not reverse an initial bias towards harmony. Our results indicate that both Control conditions provide an adequate baseline for assessing prior biases to harmony.

One difference between Experiment 4 and Experiment 4B was a significant interaction of factors in the Mid Hold-Out condition. It is unclear why this may have occurred with the different Controls, however it makes sense given the fact that participants in the Mid Hold-Out condition had fewer harmonic responses to New Vowels. It may be that the effect of this decrease in harmonic responses was not big enough to get a significant interaction in Experiment 4.

Experiment 4 provides evidence against the segment-based learning hypothesis, but does not provide complete evidence for the feature-based learning hypothesis because participants failed to generalize to low vowels. Because our effects may have been due to the fact that the suffix alternated in two feature values (back and round), we sought to disambiguate the data in Experiment 5 by employing low suffix vowels, as low vowels alternate in back only, reducing the hypothesis space to back harmony.

EXPERIMENT 5

In Experiment 5, rather than having a suffix alternation between high vowels [-mi] and [-mu], there is an alternation between low vowels [a] and [æ] with the suffixes [-mæk]/[-mak]. To maintain consistency with Experiment 4, novel vowels are heard only at test, and not in of the training stage of the experiment. Because low vowels serve as the suffix vowel in training, it is no longer possible to test generalization to low vowels as a novel segment. Therefore, the comparison for generalization to new segments must be made between mid vowels and high vowels.

The segment-based learning hypothesis predicts no generalization in either the mid or the high hold-out conditions. The general feature-based hypothesis predicts generalization to both mid and high vowels, and the interpolation-based hypothesis predicts generalization to mid vowels by interpolation of high and low vowels, but no generalization of high vowels via extrapolation of mid and low vowels.

Method

Participants

All participants were adult native English speakers with no knowledge of a vowel harmony language, and were not participants in Experiment 4. Forty-nine Johns Hopkins undergraduate students participated for extra course credit. One participant was replaced due to failure to reach criterion on the AXB perception task that followed the experiment.

Design

Final analyses included 12 participants in each of four training conditions: a High vowel Hold-Out condition, a Mid vowel Hold-Out condition, and two Control conditions one matched to the High Hold-Out (Control-High), the other matched to the Mid Hold-Out (Control-Mid).

All participants were screened based on a perceptual task to ensure that they could discriminate between front and back vowels (of the same height, high mid and low counterparts). In this simple AXB perception task, participants were asked to judge which of two vowel sounds was identical to a third sound. For example, if participants heard [ba], [ba] and [bæ], the correct response would be [ba]. All items were monosyllabic. The task was designed as a way to screen participants for the ability to perceive front-back contrasts in English, and to rule out the possibility that the results in Experiment 4 are due to difficulties in perception of front-back contrasts among low vowels. Those participants scoring less than 75 percent on this task were removed from the study, with the logic that we assume that all participants should have general competence for perceiving English vowels in order for their learning data to be meaningful. This occurred for one participant (who scored 50% on this task).

The design of the experiment was the same as Experiment 4 with following changes. The first is that the suffix changed from an alternation between front and back high vowels [-mi] and [-mu] to an alternation between front and back low vowels [-mæk] and[-mak]. The final consonant was added due to a constraint in English prohibiting lax vowels from occurring word finally. The change in suffix vowel resulted in a change in hold out conditions. In Experiment 4, there was a Mid Hold-Out and a Low Hold-Out condition; Experiment 5 contained Mid Hold-Out and High Hold-Out conditions. This ensured that the hold-out vowel was never in the training stimuli, even if it provided no evidence for or against participation in the process. This prevents participants from inferring that low vowels do not trigger harmony because low vowels are only heard as harmony targets, and never harmony triggers.

Stimuli

All new stimulus items were recorded, spliced and tested in the same manner as Experiment 4.

Procedure

The procedure was identical to Experiment 4 except that participants were given an AXB perception task for English vowel contrasts immediately following the test phase, discussed above.

Results

Proportions of harmonic responses were recorded for each subject for each of the training conditions. The mean responses for each test condition are presented in the figure in (168), below.

All feature-based learning hypotheses predicted generalization to novel mid vowels, while the segment-based learning hypothesis predicted no generalization to mid vowels in the Mid Hold-Out condition. First, overall learning was tested comparing the grand mean Mid Hold-Out to the Control-Mid participants using a two-factor mixed design analysis of variance (ANOVA) with alpha set at $p = 0.05$. The between-subjects factor was Training, with two levels in each ANOVA: the Control condition and each Hold-Out condition. Test Items (Old Stems, New Stems, New Vowel) was a within-subjects factor nested under the between-subjects factor Training. All conditions involved between-item comparisons. There was a significant effect of Training ($F(1, 22) = 22.23$,

$p < .05$); participants in the Mid Hold-Out condition made harmonic responses more often than participants in the Control-Mid condition (mean = 0.74, vs. 0.50, *CI* = ± 0.09), suggesting that participants learned the harmony pattern. There was no effect of Test Item ($F < 1$), but a significant interaction was observed ($F (2, 44) = 4.04$, $p < .05$).

Because the ANOVA showed a significant interaction, post hoc Tukey tests were performed. There was a significant difference between the Mid Hold-Out and Control-Mid participants for Old Stems ($p < 0.05$), New Stems ($p < 0.05$) and the New Vowel test items ($p < 0.001$) reflecting the overall higher proportion of harmonic responses in the Mid Hold-Out condition.

To test for generalization to novel mid vowels, we performed a t-test comparing harmonic responses in the New Vowel conditions between the Mid Hold-Out and the Control-Mid condition. There was a significant difference between New Vowel test items in the Mid Hold-Out condition and the Control-Mid participants (0.69 vs. 0.54, *CI* = ± 0.09; $t = 3.87$, $p < .001$) suggesting generalization to novel mid vowels when trained on high and low vowels.

To assess the robustness of this generalization, planned contrasts compared the New Vowel test items to the New Stems test items. If participants are just as likely to harmonize with new vowels as new stems, then there is a good reason to believe that participants have generalized from their responses. For the Mid Hold-Out condition, there was no significant difference between the New Stems and New Vowel test items (0.76 vs. 0.69, *CI* = ± 0.07; $F (1, 11) = 2.4$, $p = 0.15$). This suggests that participants showed robust generalization to mid vowels.

The interpolation-based learning hypothesis predicts no generalization to high vowels, but the feature-based learning hypothesis predicts generalization to high vowels. First, overall learning was assessed in the High Hold-Out condition using a mixed-design ANOVA, which revealed an effect for Training ($F(1, 11) = 9.87, p < .01$); participants in the High Hold-Out condition made harmonic responses more often than participants in the Control-High condition (0.67 vs. 0.52, $CI = \pm 0.096$), indicating that they were able to learn the harmony pattern. There was no effect of Test Item ($F(2, 44) = 2.75, p > .05$), and no interaction of the factors ($F < 1$).

To test for generalization to novel high vowels, a t-test was performed between the New Vowel test items between the High Hold-Out and Control-High condition. There was a significant difference between New Vowel test items in the High Hold-Out condition and the Control-High condition (0.62 vs. 0.47, $CI = \pm 0.13$; $t = 2.42, p < 0.05$) suggesting that participants are able to generalize from mid and low vowels to high vowels, supporting both the general the feature-based learning hypothesis but not the exemplar-based learning hypothesis.

To assess the robustness of generalization to novel vowels, planned contrasts were performed between New Vowel test items and New Stems test items for the High Hold-Out condition. There was no significant difference between the New Stems and New Vowel (0.72 vs. 0.66, $CI = \pm 0.07$; $F < 1$) test items, suggesting robust generalization to high vowels.

To test whether there was a significant difference between the two Control conditions, we performed a mixed-design ANOVA. There was no effect of Training

(0.50 vs. 0.52, *CI* = ± 0.02; $F < 1$) or Test Item ($F < 1$). There was a significant interaction ($F(2, 44) = 3.39$, $p < 0.05$).

Perception (AXB) results were at ceiling. High vowel contrasts were at 96.7 percent; mid vowel contrasts were at 94.9 percent and low vowel contrasts were at 96.9 percent. These results show that participants are able to differentiate between [i] and [u], between [e] and [o], and, critically, between [æ] and [a], indicating that it is unlikely that poor performance for low vowels in Experiment 4 was due to perceptual difficulty associated with those vowels.

Discussion

As with Experiment 4, the results of Experiment 5 are inconsistent with segment-based learning. The fact that learners generalized to new vowels in both the High Hold-Out and the Mid Hold-Out conditions supports the general feature-based learning hypothesis, but does not support the interpolation-based approach that predicts no generalization to high vowels.

While it appears that learners used a more specific feature-based strategy for Experiment 4 than in Experiment 5, we argue that learners made use of the feature values of the alternating suffix (back and round). Learners do not always form fully general rules, nor due they always form specific rules. In Experiment 4, learners did not generalize to low vowels, because low vowels do not alternate in the same way as the suffix exemplar ([mi]/[mu]); high vowels alternate in round and back, but low vowels only alternate in the feature back. In Experiment 5, participants generalized to high vowels, as high vowels are able to participate in pure back harmony.

Experiments 4 and 5 provide evidence that subsegmental features are used in phonological learning. However, it is still possible that the patterns that learners identified in these experiments nevertheless lack the sort of generality that a richer array of data would motivate. For example, in Experiments 4-5, participants were exposed only to a single affix alternation (e.g., [-mi] vs. [-mu]). It remains possible that participants simply learned to associate a specific suffix form and a type of stem (e.g., front vowels trigger [-mi], back vowels trigger [-mu]), rather than a formally general harmony alternation of the kind formalized by phonologists. If learners posit formal, abstract processes, they should be able to extend the harmony pattern to novel suffixes as well. This is explored in Experiment 6.

EXPERIMENT 6

Method

Participants

All participants were adult native English speakers with no knowledge of a vowel harmony language, and did not participate in any other vowel harmoy experiment. Thirty-seven Johns Hopkins undergraduate students participated for extra course credit. Participants were randomly assigned to one of three training conditions: a Control condition containing mixed harmony stems, a High Vowel Suffix condition and Mid Vowel Suffix condition. Final analyses included 12 participants in each condition. All participants were screened based on a perceptual (AXB) task. Those participants scoring less than 75 percent on this task were removed from the study. This occurred for one participant.

Design

The design of the experiment was the same as Experiments 4-5, but with a few important differences. The first is that the harmony alternation was unambiguously round/back; only non-low vowels (which alternated in both round and back) occurred in the stimuli ([i, u], [e, o]). Second, rather than creating hold-out conditions that applied to the stems, the suffix varied between conditions between high ([-mi]/[-mu] or [-gi]/[-gu]) and mid ([-me]/[-mo] or [-ge]/[-go]). However, there were no hold-out stem vowels: all conditions contained four vowels [i, u, e, o] at both training and at test. Participants in each hold-out condition were exposed to one suffix, and were asked to generalize to one novel suffix. The novel suffix always contained a different vowel, and a different consonant than the training suffix. For example, if a participant was trained with a [-mi]/[-mu] alternation, they were tested on the [-ge]/[-go] alternation, and vice versa. Participants trained on [-gi]/[-gu] were tested on [-me]/[-mo] and vice versa. The suffix consonant was varied to ensure that generalization to novel suffixes did not depend on similarity to the training suffix (i.e., had the same consonant). Training was counterbalanced such that half of the participants in each condition received a suffix beginning with the bilabial nasal [m] ([-mi]/[-mu], [-me]/[-mo]) and the other half were trained using suffix beginning with a velar stop [g] ([-gi]/[-gu], or [-ge]/[-go]). Participants in the Control condition were also counterbalanced to receive test items including [-me]/[-mo] and [-gi]/[-gu], or test items using the suffixes [-mi]/[-mu] and [-ge][-go]. This gave us two different training conditions: Mid Hold-Out and High Hold-Out.

The experiment finished with the same AXB perception task as in Experiment 6.

Stimuli

The stimuli were of the same type as Experiments 4-5. All new items were prepared in the same manner as Experiments 4-5.

Procedure

The procedure was identical to Experiment 5; the AXB task occurred following test. Participants were given a break before beginning the AXB task after testing.

Results

Percent of harmonic responses were recorded for each subject for each of the training conditions. The mean responses for each test condition are presented in the figure in (169), below.

First, we assessed the overall effect of training on all participants using a mixed design two-factor ANOVA with alpha set at $p = 0.05$. The between-subjects factor was Training, with two levels in each ANOVA: the Control condition and each Hold-Out condition. Test Items (Old Stems, New Stems, New Suffix) was a within-subjects factor nested under the between-subjects factor Training. All conditions involved between-item comparisons.

For the ANOVA comparing Controls to the High Hold-Out condition, there was a significant effect of Training ($F (1,22) = 51.88$; $p< 0.001$), in that participants in the High Hold-Out condition (mean = 0.81 vs. 0.50, $CI = \pm 0.083$) were more likely to choose the harmonic option than participants in the Control condition, suggesting an overall effect of training. For the ANOVA comparing Controls to Mid Hold-Out, there was a significant effect of Training ($F (1, 22) =37.44$, $p < 0.001$); participants in the Mid Hold-Out condition (mean = 0.84 vs. 0.50, $CI = \pm 0.049$) were more likely to choose the harmonic candidate than participants in the Control condition, suggesting an overall effect of training.

To assess generalization to novel suffix vowels, a t-test was performed comparing the New Suffix condition of the Control condition to the New Suffix condition for each training condition. There was a significant difference between New Suffix test items and Controls (0.72 vs. 0.47; $CI = \pm 0.12$; $t = 3.65$, $p < .001$) for the High Hold-Out condition as well as the Mid Hold-Out condition (0.76 vs. 0.47, $CI = \pm 0.13$; $t = 4.49$, $p < 0.001$) in that participants were more likely to select the harmonic choice for New Suffix test items compared to Controls, suggesting generalization to novel suffixes for both conditions.

To assess the robustness of this generalization, contrasts were made within each condition comparing New Stems test items each to New Suffix test items. For the Mid Hold-Out condition, there was a significant difference between New Stems and New Suffix (0.86 vs. 0.76, $CI = \pm 0.087$; $F(1, 11) = 6.04$, $p < 0.05$) in that participants performed better on New Stems. For the High Hold-Out condition, there were no differences between the New Stems and New Suffix test items (0.83 vs. 0.72, $CI = \pm 0.082$; $F(1, 11) = 3.31$, $p > 0.05$), suggesting a robust generalization to novel high vowel suffixes.

To assess whether learning and generalization to novel suffixes was the same for both training conditions, we compared the High Hold-Out to Mid Hold-Out (0.81 vs. 0.84, $CI = \pm 0.13$) using the same two-factor ANOVA. There were no effects for Training ($F < 1$), and no interaction ($F < 1$), suggesting equivalent learning for both conditions. There was an effect of test item ($F(2,44) = 11.72$, $p < 0.01$). There was a significant difference between New Stems and New Suffix items ($F(2, 44) = 8.38$, $p < 0.01$), suggesting less harmonic performance to New Suffix items overall.

Discussion

The results from Experiment 6 indicate that participants have learned a general, robust harmony alternation between front unround vowels versus back round counterparts, and were able to extend this pattern to novel suffixes that differed in vowel height from the training suffixes. While harmonic responses to Novel Suffixes were significantly above chance (as established by comparison to the control condition), these responses were significantly less harmonic than responses to New Stem items (but only in the Mid Hold-Out condition). This is different from the previous experiments in which generalization to a novel vowel tended to be as good as generalization to an old stem (except for high vowels in Experiment 5). There are several potential explanations for this. First, the proportion of harmonic responses on new suffix items was relatively high compared to previous experiments, suggesting that even if participants are able to extend the pattern to novel items, it is unlikely that they will extend it at such a high level. Second, the novel suffix was different from the exemplar suffix on two dimensions, the vowel and the consonant. Since the alternation was given in terms of the suffix allomorphs, it is not surprising that the process is more robust for the exemplar suffix then for a novel suffix. The fact that participants were able to extend the vowel harmony pattern to novel suffixes provides evidence that the harmony process was more abstract than a literal stem to suffix association.

The results of this experiment provide further evidence that learning is abstract. Not only are participants able to generalize to novel harmony triggers (novel stem vowels), but also harmony targets in novel suffix vowels. This finding is also significant because previous experiments in artificial grammar learning have not tested for this level of generalization.

GENERAL DISCUSSION:

Understanding the level of generalization that learners make in artificial language experiments may shed light on how natural classes are represented in the mind. The results of the present experiments suggest that learners make use of feature-based representations in learning a novel phonological process. However, learners may use additional principles to make inferences about the whether a novel segment should participate in the harmony process. The substantively biased approach to learning (Finley & Badecker, 2008; Wilson, 2006) claims that phonetic factors such as articulatory ease as perceptual contrasts combined with covert knowledge of grammatical structures guide learners to form particular generalizations about phonological processes. These principles are a potential source for the universal factors that could plausibly give rise to the principled typology of grammatical processes found cross-linguistically.

Support for the substantively biased approach to learning is present in the differential generalization found in Experiment 4, in which learners made constrained sub-segmental inferences about the harmony pattern. Participants posited a round harmony pattern that did not apply to low vowels, demonstrating learners' awareness that mid vowels share the back/round contrast found in the exemplar suffix alternations, but that low vowels do not share this back/round contrast and therefore cannot participate in back/round harmony. This suggests that learners use the features involved in the morphophonological alternations they are exposed to in order to infer a phonological process.

The fact that low vowels failed to participate in the back/round harmony system in Experiment 4 correlates with the cross-linguistic fact that low vowels rarely participate in round harmony (Kaun 2004). This typological generalization may stem from learning biases against low vowels as undergoers for round harmony. This bias may arise as a result of the difficulty of perceiving and articulating the round feature on low vowels, and may also explain the fact that vowel inventories are unlikely to include rounding contrasts in low vowels. These language-specific and universal phonetic factors may lead learners to form substantive biases or expectations about the most likely form of a novel grammar.

In this paper, we argue against a learning strategy that makes use only of interpolation of phonological features and phonetic forms, as hypothesized by exemplar-based theories of learning, as participants in Experiment 5 extrapolated from mid and low to high vowels. It is tempting, in light of the results of our experiments, to simply revise the interpolation-based model to account for the experimental data, and allow for occasional generalization beyond the exemplar training space. The only principled way to predict when extrapolation occurs is to incorporate additional biases into the learner. Such biases must be of a similar nature as the principles that define the substantively biased learner. The only true difference between a modified interpolation-based learner and a substantively biased learner is the relative role of abstract representations and phonetic principles in making predictions about the nature of phonological learning. More research is needed to distinguish between these two hypotheses.

Contradictory Results in Previous Research

The experiments presented in this study provide strong evidence against a segment-based learning approach; participants generalized to novel segments in several conditions. This finding is different from the findings of Peperkamp, Skoruppa and Dupoux (in press) and Peperkamp and Dupoux (2006), in which no generalization for novel segments were found. There are a number of reasons why this disparity might be expected, though. In Peperkamp and Dupoux's (2006) study, participants were exposed to an intervocalic voicing alternation, in which either fricatives or stops (but never both) would become voiced between vowels. The data for this process was presented as an alternation of the initial consonant of a noun in the presence of a preceding vowel-final or consonant-final determiner. The process applied to stems across word boundaries. In our experiments, the alternation applied to affixes across morpheme boundaries. It may be that learners are more reluctant to apply a phonological change to whole words, especially across word boundaries. It is widely observed cross-linguistically that affixes are more likely to undergo changes than stems (J. N. Beckman, 1997). In our experiments, participants were only asked to choose between two suffix allomorphs, while in Peperkamp et al. (in press), participants had to choose between alternation and non-alternation. It is possible that learners are biased against alternations, especially to novel items, making generalization less likely.

Second, Peperkamp et al. (in press) and Peperkamp and Dupoux (2006) exposed participants to the entire inventory at training, but only a subset of this inventory was found in environments where the pattern should apply; the other segments were found in environments where the process could not apply. It may be that learners treat segments that are only presented in non-alternating contexts as resistant to alternation. They may view the fact that they have seen the segment, but never seen it undergo the process as negative evidence. In the experiments presented in this paper, participants had no exposure to the novel vowel until the testing phase of the study, which would have weakened this type of inference.

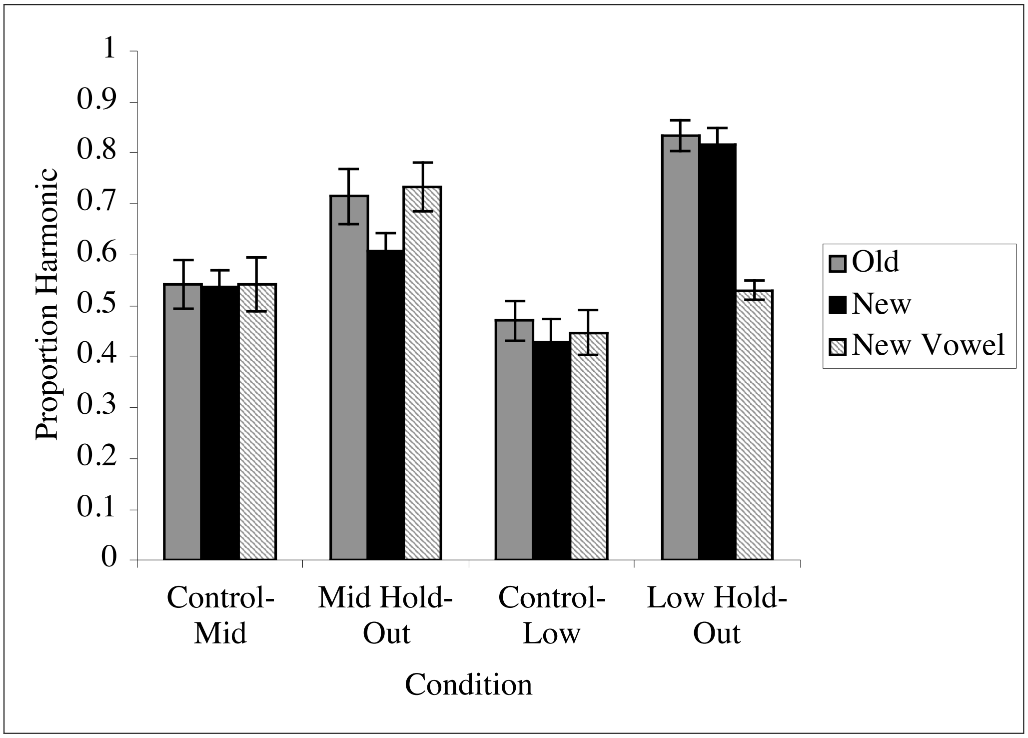
Finally, the patterns that Peperkamp et al. (in press) presented to their participants involved consonants, while the patterns in our experiments involved vowels. It is possible that the continuous feature space found in vowels may make it easier for participants to learn a general rule, while the discrete consonant space may lead participants to prefer segment-based learning. However, Goldrick (2004) did find limited generalization with novel coronal consonants. It may be that generalization to novel consonants is possible but highly constrained.

Summary

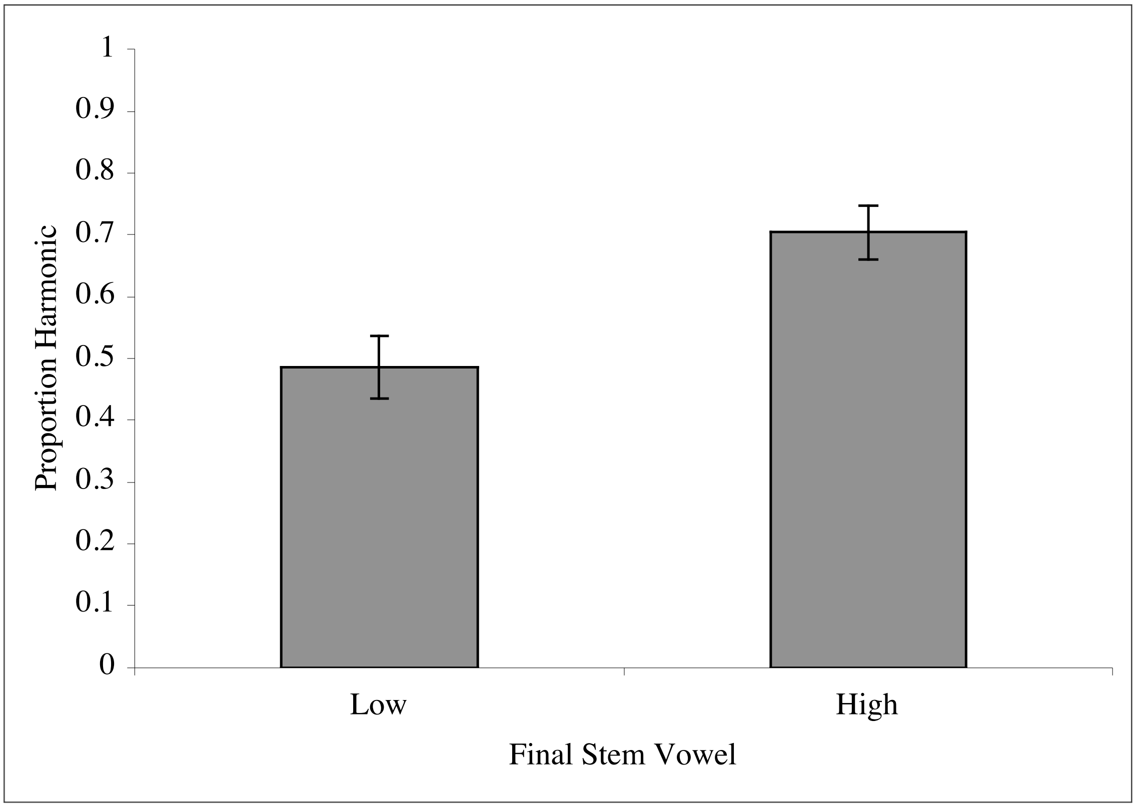
This chapter describes the results of three experiments testing the generalization to novel segments through artificial grammar learning in adults. We specifically manipulated training and test items to systematically vary whether the test items appeared in training, were novel or were both novel and contained novel segments. The results support a feature-based learning mechanism that makes use of general, substantive principles of phonetics and phonological structure.

The status of features and natural classes is an important issue in theoretical phonology. For example, the features that derive a language's segment inventory may regulate the possible types of phonological processes that are found in that language (Moren, 2003). A theory of universal phonological features makes different predictions than a theory of language-specific features about the type of process that can be learned. Future experimental work may help provide insight into the issue of language-specific features by providing novel data, and a means for further testing the predictions that theories of features and phonological alternations make about the learning process.

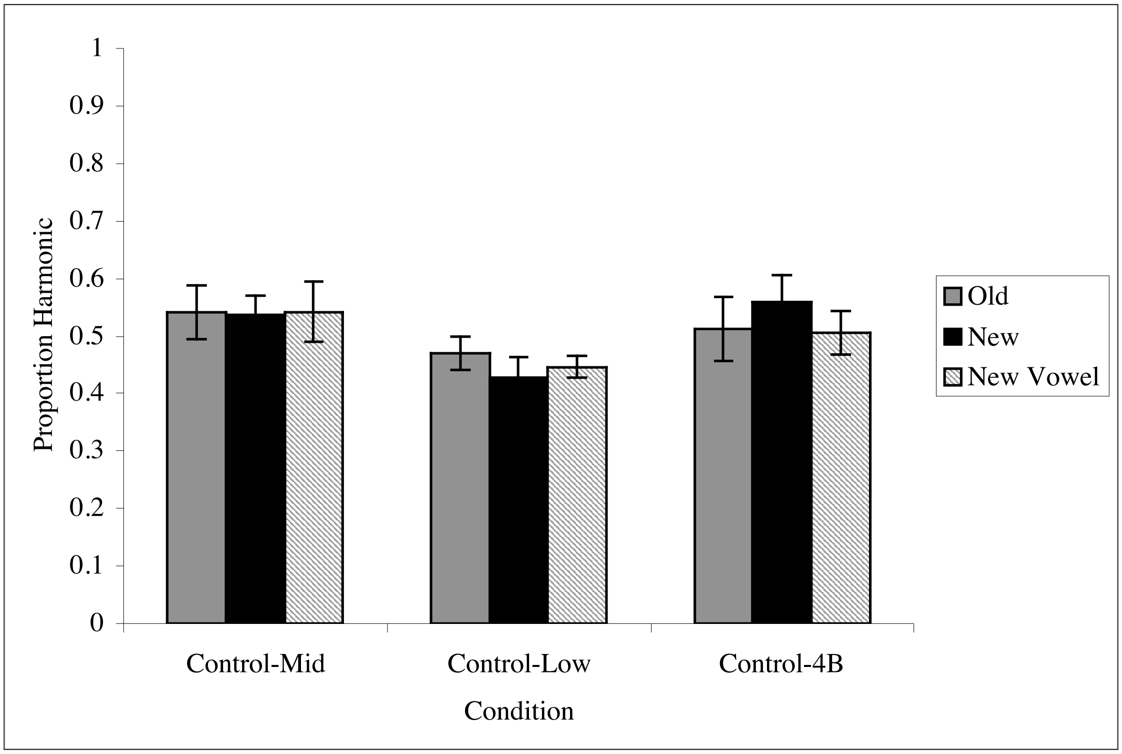
(165) *Figure 1*: Proportion of Harmonic Responses for All Conditions: Experiment 4



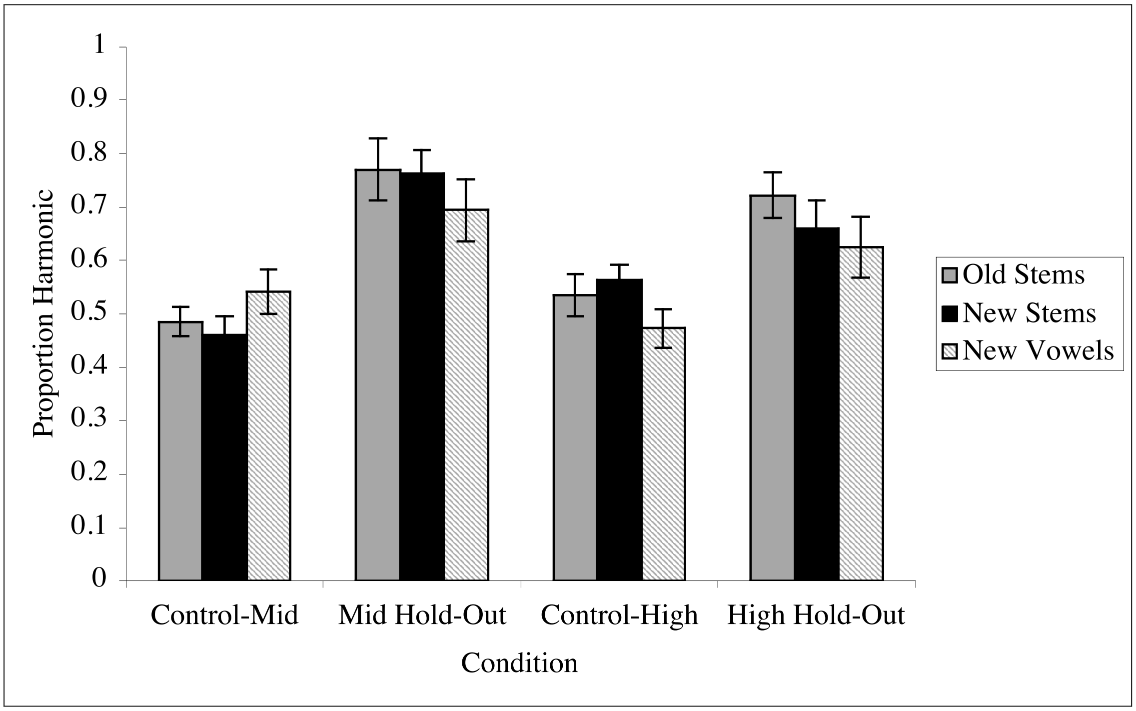
(166) *Figure 2*: Comparison of means between low and high vowel stems for New Stems in the Mid Hold-Out condition, Experiment 4



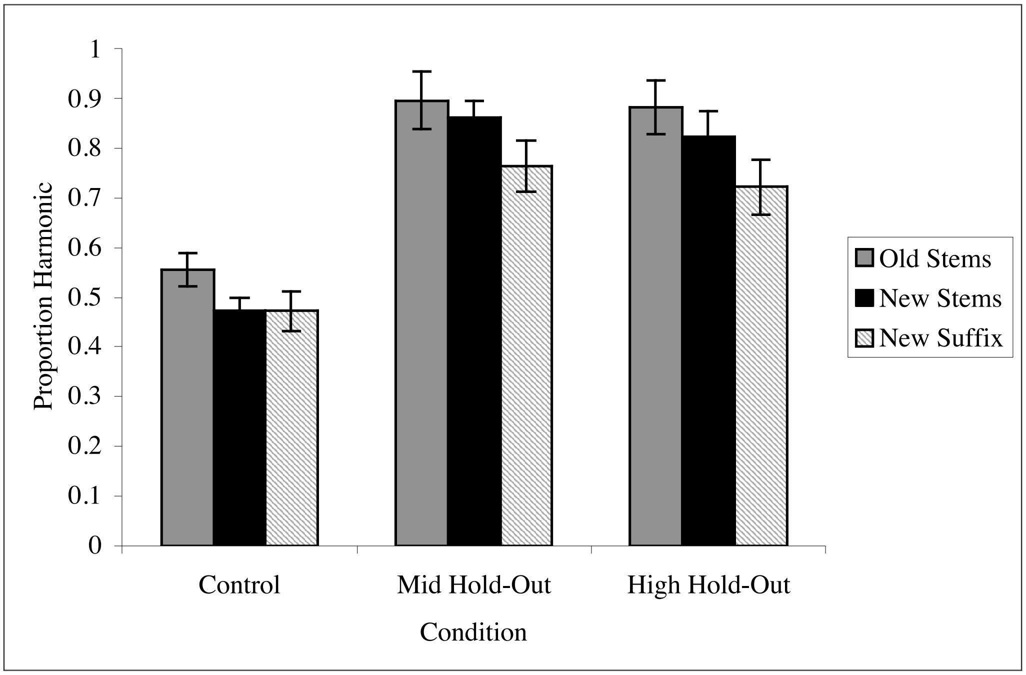
(167) Figure 3: Comparison of Results from Experiment 4 to Experiment 4B



(168) *Figure 4*: Proportion of Harmonic Responses for All Conditions: Experiment 5



(169) Figure 5: Proportion of Harmonic Responses for All Conditions: Experiment 6



(170) Table 1: Examples of Training and TestStimuli for Test Conditions in Experiment 4

Front Vowels	Back Vowels
Mid Hold Out	
[bidi] [bidimi]	[tudu] [tudumu]
[pædi] [pædimi]	[madu] [madumu]
Low Hold-Out	
[nege] [negemi]	[gomo] [gomomu]
[degi] [degimi]	[muto] [mutomu]

(171) Table 2: Examples of Test Stimuli in Experiment 4

	Mid Hold-Out	Low Hold-Out
Old	[bidimi] [bidimu]	[bidimi] [bidimu]
	[pædimi] [pædimu]	[negemi] [negemu]
New	[dinimi] [dinimu]	[dinimi] [dinimu]
	[tanumu] [tanumi]	[penimi] [penimu]
New Vowel	[podomu] [podumi]	[dapamu] [dapami]
	[negemi] [negemu]	[kætæmi] [kætæmu]

(172) Table 3: Design and Example Stimuli for Experiment 4

	Training Items	Novel Suffix Test Items
Mid Suffix Hold-Out	[bidemi],[bodumu]	[bidige],[bodogo]
	[pedigi],[podogu]	[pedime],[podomo]
High Suffix Hold-Out	[nepege],[nopugo]	[nepemi],[nopumu]
	[dinime],[dunumo]	[dinigi],[dunugu]
Control	[pedi], [duni]	[pedigi],[podogu]
	[pedi], [duni]	[dinime],[dunumo]
	[pedi], [duni]	[bidemi],[bodumu]
	[pedi], [duni]	[nepege],[nopugo]

Appendix 1: Experiment 4 Stimuli

Mid Hold-Out Training Items	Low Hold-Out Training Items	
piki	beme	
midi	bimi	
bimi	buno	
kaetae	degi	
naegae	doku	
gaemae	gibe	
punu	gomo	
tudu	kete	
mubu	kine	
gata	kugo	
dapa	midi	
bada	mobo	
tipae	mubu	
kinae	muto	
gibae	nege	
paedi	neki	
naeki	nopu	
daegi	pedi	
kuga	piki	
muta	podo	
buna	punu	
daku	tipe	
tanu	tonu	
napu	tudu	
Test-Mid Hold-Out		
Old	New	New Vowel
gibae	kipae	beme
kaetae	naebae	kete
tudu	dutu	nepe
bada	taba	podo
naegae	baekae	gomo
paedi	paemi	tono
muta	guta	deke
dapa	maga	mobo
tanu	madu	pete
bimi	budu	kopo
midi	dini	mogo
punu	tidi	nege

Test-Low Hold-Out

Old	New	New Vowel
gibe	kipe	gaemae
kete	nepe	kaetae
tudu	dutu	naegae
podo	tono	dapa
nege	deke	bada
degi	pemi	taba
muto	guto	baekae
gomo	mogo	maga
punu	budu	kana
midi	dini	naebae
bimi	tidi	gata
nopu	modu	taepae

Appendix 2: Experiment 5 Stimuli

High Hold-Out Training Items	Mid Hold-Out Training Items
bada	piki
dako	midi
maede	bimi
tano	kaetae
kaetae	naegae
mepe	gaemae
boka	punu
gebae	tudu
kenae	mubu
podo	gata
gaemae	dapa
dapa	bada
poga	tipae
gata	kinae
pomo	gibae
moka	paedi
beme	naeki
daege	daegi
tebae	kuga
tono	muta
naegae	buna
napo	daku
kete	tanu
naeke	napu

Test Items:
High Hold-Out

Old	New	New Vowel
gebae	kepae	piki
kaetae	naebae	midi
pomo	pete	bimi
bada	taba	punu
naegae	baekae	tudu
daege	paeme	mubu
moka	gota	kipi
dapa	maga	nubu
tano	mado	dutu
beme	kopo	budu
nege	deke	dini
podo	mobo	tidi

Test Items:
Mid Hold-Out

Old	New	New Vowel
gibae	kipae	beme
kaetae	naebae	kete
tudu	dutu	nepe
bada	taba	podo
naegae	baekae	gomo
paedi	paemi	tono
muta	guta	deke
dapa	maga	mobo
tanu	madu	pete
bimi	budu	kopo
midi	dini	mogo
punu	tidi	nege

Appendix 3: Experiment 6 Stimuli

Training Items
kete
bimi
beme
gomo
podo
mobo
tipe
kine
gibe
pedi
neki
midi
degi
mubu
kugo
muto
buno
doku
tonu
punu
nopu
nege
tudu
piki

Test Items:

Old Stems	New Stems	New Suffix Vowel
gibe	budu	piki
bimi	dini	mobo
gomo	deke	bunu
nopu	mogo	doku
punu	modu	tipe
podo	pemi	tonu
nege	dutu	neki
pedi	tono	midi
kine	kipe	kete
muto	tidi	kugo
degi	nepe	beme
tudu	guto	mubu

Chapter 10: Experiments in Round Harmony Typology (Experiments 7-8)

The results of Experiment 6 indicate that participants are able to extend novel patterns to novel suffixes. This suggests that learners are sensitive to novel harmony targets, because the suffix vowel is the target for harmony. Given that the stem vowel triggers harmony and the suffix vowel is the target for harmony, it is possible to test learners' sensitivity to triggers and targets in vowel harmony.

It may be tempting to interpret the result that learner's form hypotheses for phonological processes in line with typological predictions as an effect of direct knowledge of typological frequency. Because the factors that lead to typological distributions (articulatory ease, perceptibility, learnability, etc.) are so tightly linked to typological frequencies themselves, it is possible that learners actually encode relative typological frequencies. The present experiments are attempt to differentiate between these two hypotheses.

In round harmony, there is an asymmetric difference between the type of vowel that spreads harmony and the type of vowel that undergoes harmony. High vowels are the best targets for round harmony, but mid vowels are the best triggers for round harmony (Kaun, 1995, 2004). High vowels are more likely to undergo harmony because high round vowels are relatively unmarked; a high round vowel is more likely to be in the inventory than a non-high round vowel. If round can only spread to vowels that can take on the round feature (i.e., the round vowel is in the inventory), then spreading to high vowels will be more likely because high round vowels are more likely to be in the inventory. Mid round vowels, on the other hand, are perceptually weak. By spreading their round feature, mid round vowels are more likely to be perceived as round. The idea is that if round is difficult to hear on one mid vowel, then spreading it to a second vowel gives a second opportunity to perceive the round feature.

In Experiments 7 and 8, we test substantive biases towards high targets to round harmony and non-high triggers to round harmony, respectively. In Experiment 7, participants are exposed to round harmony where both non-high and high stems trigger harmony to either a high suffix or a non-high suffix. Participants are tested on their generalization to novel suffix vowels, either high or mid, depending on their training.

EXPERIMENT 7

Experiment 6 tested generalization to novel suffixes and compared generalization to mid versus high vowel suffixes; no difference was found. This may be because stems contained a mixture of mid and high vowels. For example, the stem [budo] shows left to right spreading from high to mid. This poses the possibility that participants learned that spreading from high to mid and mid to high is possible based on evidence from the stem. Experiment 7 eliminates this interaction through the use of stems with identical vowels (e.g., [budu], [bodo]).

There may be another reason why participants in Experiment 6 were able to generalize to novel suffixes in both the mid and high hold-out conditions. In Kaun's (2004) analysis of round harmony, what determines whether a vowel will undergo harmony is inventory constraints. In her analysis, the only way that mid round vowels will not be a target for harmony is if they do not exist in the inventory. In our experiments, participants are exposed to the mid round vowel [o] in the stems. This means that when participants are exposed to mid vowel suffixes for the first time, they should already know that mid round vowels are allowed in the inventory of the novel language, and should have no restriction on whether mid vowels participate.

If substantive biases are based purely in typological frequency, we should expect learners to behave differently in the two target hold-out conditions; they should generalize to novel high vowels, but not to novel mid vowels. However, if biases are based on inventory constraints, then participants should generalize to both high and mid vowel suffixes. This allows us to differentiate between the two hypotheses that substantive biases are derived via constraints on inventory (and other phonetically motivated knowledge) or if they are derived via direct knowledge of typological frequencies.

Method

Participants

All participants were adult native English speakers with no knowledge of a vowel harmony language. Forty-one Johns Hopkins undergraduate students participated for extra course credit, and did not participate in previous harmony experiments. Participants were randomly assigned to one of three training groups: a Control group containing mixed harmony stems, a High Vowel Suffix condition and Mid Vowel Suffix condition. Final analyses included 20 participants in each group. All participants were screened based on a perceptual (AXB) task. Those participants scoring less than 75 percent on this task were removed from the study. This occurred for one participant.

Design

The design of the experiment was the same as Experiment 4, except that all stems contained identical vowels. This was done to eliminate the potential confound that participants in Experiment 3 were able to generalize to novel suffixes in both conditions because stem vowels contained evidence of spreading to both mid and high vowels. Participants in each hold-out condition were exposed to one suffix, and were asked to generalize to one novel suffix. The novel suffix always contained a different vowel, and a different consonant than the training suffix. For example, if a participant was trained with a [-mi]/[-mu] alternation, they were tested on the [-ge]/[-go] alternation, and vice versa. Participants trained on [-gi]/[-gu] were tested on [-me]/[-mo] and vice versa. The suffix consonant was varied to ensure that generalization to novel suffixes did not depend on similarity to the training suffix (i.e., had the same consonant). Training was counterbalanced such that half of the participants in each condition received a suffix vowel with the bilabial nasal [m] ([mi]/[mu], [me]/[mo]) and the other half were trained using suffix involving a velar stop [g] ([gi]/[gu], or [ge]/[go]). Participants in the Control condition were also counterbalanced to receive test items involving including [me]/[mo] and [gi]/[gu], or test items using the suffixes [mi]/[mu] and [ge][go]. Examples of training and test stimuli for Experiment 7 are provided in the tables in (173) and (174) below.

(173) Training Stimuli: Experiment 7

bimi
pidi
duku
kete
piki
tepe
tunu

(174) Test Stimuli: Experiment 7

dutu
goto
kepe
mudu
mogo
tono

The experiment finished with the same AXB perception task as in Experiment 4.

Stimuli

As mentioned above, the stimuli were of the same type as Experiments 4, with the exception that stem vowels were identical.

Procedure

The procedure was identical to Experiment 6. Participants were given a break before beginning the AXB task after testing.

Results

Percent of harmonic responses were recorded for each subject for each of the training conditions. The mean responses for each test condition are presented in the figure found in (177), below.

Participants in the Control condition were compared to participants in each of the training conditions via a separate mixed design two-factor analysis of variance (ANOVA) with alpha set at $p = 0.05$. The between-subjects factor was Training, with two levels in each ANOVA: the Control group and each Hold-Out condition. Test Items (Old Stems, New Stems, New Suffix) was a within-subjects factor nested under the between-subjects factor Training. All conditions involved between-item comparisons.

For the ANOVA comparing Controls to the High Hold-Out condition, there was a significant effect of Training ($F (1, 38) = 652.70$; $p < 0.001$), in that participants in the High Hold-Out condition were more likely to choose the harmonic option than participants in the Control condition (70.56 vs. 0.47.63). There was no effect of Test Item ($F (2, 38) = 2.41$, $p > 0.05$). There was no interaction ($F (2, 76) = 1.36$, $p > 0.05$).

For the ANOVA comparing Controls to Mid Hold-Out, there was a significant effect of Training ($F (1, 38) = 19.01$, $p < 0.001$); participants in the Mid Hold-Out condition (mean = 74.03) were more likely to choose the harmonic candidate than participants in the Control condition. There was no effect of Test Item ($F (2, 38) = 2.53$, $p > 0.05$) and no interaction ($F < 1$).

For the ANOVA comparing High Hold-Out to Mid Hold-Out, there were no effects for Training ($F < 1$), and no interaction ($F < 1$). There was an effect of Test Item ($F (2, 38) = 8.45$, $p < 0.001$).

To assess generalization, a t-test was performed comparing the New Suffix condition of the Control condition to the New Suffix condition for each training condition. There was a significant difference between New Suffix test items and Controls ($t = 3.46$, $p < .01$) for the High Hold-Out condition as well as the Mid Hold-Out condition ($t = 3.31$, $p < 0.001$) in that participants were more likely to select the harmonic choice for New Suffix test items compared to Controls.

To further assess generalization, contrasts were made within each condition comparing Old Stems and New Suffix test items each to New Suffix test items. For the Mid Hold-Out condition, there was no significant difference between New Stems and New Suffix (0.75 vs. 0.68; $F (1, 19) = 3.52$, $p > 0.05$), as well as a significant difference between Old Stems and New Suffix test items (0.79 vs. 0.68; $F(1, 19) = 6.35$, $p < 0.05$). For the High Hold-Out condition, there was a significant difference between either the New Stems and New Suffix test items (0.71 vs. 0.65; $F(1, 19) = 4.41$, $p < 0.05$). There was a significant difference between the Old Stems and New Suffix (0.75 vs. 0.65; $F(1, 19) = 13.05$, $p < 0.001$) test items.

<u>Discussion</u>

The results from Experiment 7 replicate the results from Experiment 6; participants appear to have learned a general, robust round harmony rule, and were able to extend this rule to novel suffixes. While harmonic responses to Novel Suffixes were significantly above chance (as established by the Control condition), these responses were significantly less harmonic than responses to Old Stem items. Participants were able to generalize in both the mid and high hold-out conditions, indicating that learning is sensitive to inventory constraints, rather than pure typological restrictions. This suggests that substantive biases are much more complex than a simple listing of typological frequencies. It also leaves open the possibility that at least some portion of substantive biases are acquired rather than innately specified (and vice versa). The finding that speakers are not always sensitive to cross-linguistic frequencies of patterns has important implications for phonological theory. A psychologically real theory of phonology need not directly encode typological frequencies in the grammar; rather these frequencies can be derived from other substantive facts such as inventory constraints and perceptibility.

While the asymmetry between high and mid vowel targets is explained in terms of inventory constraint, the asymmetry for harmony triggers cannot be explained using inventory constraint. Kaun's (2004) analysis of round vowel harmony explains the fact that mid vowels are more likely harmony triggers with the specific constraint [–HIGH]-SPREAD-[Round] (non-high vowels must spread round). The prediction then is that if learners are sensitive the constraints on round harmony that are independent of the inventory, learners should be able to generalize from high triggers to mid triggers, but not vice versa. Experiment 8 tests this prediction.

EXPERIMENT 8

Method

Participants

All participants were adult native English speakers with no knowledge of a vowel harmony language. Sixty-eight Johns Hopkins undergraduate students and affiliates participated either for extra course credit or for $7 and did not participate in any other experiments presented in the dissertation. Participants were randomly assigned to one of three training groups: a Control group containing mixed harmony stems, a High Vowel Suffix condition and Mid Vowel Suffix condition. Final analyses included 12 participants in each group. All participants were screened based on a perceptual (AXB) task. Those participants scoring less than 75 percent on this task were removed from the study. This occurred for four participants.

Design

The design of the experiment was identical to Experiment 7, except that participants in each hold-out condition were exposed to two suffixes, one high and one mid, and were exposed to stems of only a single vowel height (mid or high). Participants were tested on generalization to stems with a novel vowel height. The two suffixes always contained a different vowel, and a different consonant. Participants were trained on either [-mi]/[-mu] and [-ge]/[-go] alternations, or [-gi]/[-gu] and [-me]/[-mo]. Training was counterbalanced such that half of the participants in each condition received [-mi]/[-mu] and [-ge]/[-go] and the other half received [-gi]/[-gu] and [-me]/[-mo]. Participants in the Control condition received disharmonic stems from both vowel heights, and were also counterbalanced to receive identical test from the High Hold-Out condition and the Mid Hold-Out condition. Examples of training and test stimuli for Experiment 8 are provided in the tables in (175) and (176) below.

(175) Training Stimuli: Experiment 8

Mid Hold-Out	**High Hold-Out**	**Suffix**
kini	kene	mi/mu
niki	nege	mi/mu
pimi	pete	mi/mu
bidi	beme	mi/mu
piki	podo	ge/go
tunu	tepe	ge/go
bimi	bene	ge/go
tigi	dete	ge/go

(176) Test Stimuli: Experiment 8

Test Stimuli	**Mid Hold-Out**	**Suffix**	**High Hold-Out**	**Suffix**
New	budu	ge/go	goto	ge/go
New	nuku	ge/go	pete	ge/go
New	duku	mi/mu	tepe	mi/mu
New Vowel	bono	ge/go	midi	ge/go
New Vowel	beme	mi/mu	nupu	ge/go
New Vowel	mobo	ge/go	punu	ge/go
Old	bidi	mi/mu	kogo	ge/go
Old	nupu	ge/go	gomo	mi/mu
Old	punu	ge/go	gebe	ge/go

The experiment finished with the same AXB perception task as in Experiment 7.

Stimuli

As mentioned above, the stimuli were of the same type as Experiments 7, with the exception that training consisted of two suffix vowel heights, and stems had one vowel height, depending on training.

Procedure

The procedure was identical to Experiment 7. Participants were given a break before beginning the AXB task after testing.

Results

Percent of harmonic responses were recorded for each subject for each of the training conditions. The mean responses for each test condition are presented in the figure in (178), below.

Participants in the Control condition were compared to participants in each of the training conditions via a separate mixed design two-factor analysis of variance (ANOVA) with alpha set at $p = 0.05$. The between-subjects factor was Training, with two levels in each ANOVA: the Control group and each Hold-Out condition. Test Items (Old Stems, New Stems, New Suffix) was a within-subjects factor nested under the between-subjects factor Training. All conditions involved between-item comparisons.

For the ANOVA comparing Controls to the High Hold-Out condition, there was a significant effect of Training ($F(1, 40) = 8.82$; $p < 0.05$), in that participants in the High Hold-Out condition were more likely to choose the harmonic option than participants in the Control condition (mean = 0.50 vs. 0.62; CI = ± 0.051). There was an effect of Test Item ($F(2, 80) = 3.53$, $p < 0.05$). There was no interaction ($F(2, 80) = 1.77$, $p > 0.05$).

For the ANOVA comparing Controls to Mid Hold-Out, there was no effect of Training ($F(1, 40) = 2.76$, $p > 0.05$); participants in the Mid Hold-Out condition were as likely to choose the harmonic candidate than participants in the Control condition (mean = 0. vs. 0.50, CI = ± 0.043). There was also no effect of Test Item ($F(2, 80) = 2.33$, $p > 0.05$); there was no interaction ($F(2, 80) < 1$, $p > 0.05$).

For the ANOVA comparing High Hold-Out to Mid Hold-Out, there was no effect of Training ($F(1, 40) = 2.77$, $p > 0.05$) (FIX CI). There was an effect of Test Item ($F(2, 80) = 6.45$, $p < 0.01$). There was no interaction ($F(2, 80) < 1$).

To assess generalization, a t-test was performed comparing the New Suffix condition of the Control condition to the New Suffix condition for each training condition. There was no significant difference between New Suffix test items and Controls ($t(40) < 1$) for the High Hold-Out condition or for the Mid Hold-Out condition ($t(40) < 1$) in that participants were as likely to select the harmonic choice for New Suffix test items as the Controls.

To further assess generalization, contrasts were made within each condition comparing New Stems and to the New Vowel test items. For the High Hold-Out condition, there was a significant difference between New Stems and New Vowels (0.67 vs. 0.54; $F(1, 20) = 7.16$, $p < 0.05$), confirming a lack of generalization to novel vowels. Because there was no effect of training in the Mid Hold-Out condition, we expect no difference between novel items and novel vowel items. We found no significant difference between the New Stems and New Vowel test items (0.56 vs. 0.49; $F(1, 20) = 1.79$, $p > 0.05$), confirming that generalization to novel high vowels is no more difficult than extending the harmony pattern to novel stems. This also confirms that the lack of an effect of Training for the High Hold-Out condition compared to the Control condition was not due to poor performance on the Novel Vowel test items.

Discussion

The results from Experiment 8 suggest that learning that high vowels trigger harmony (the Mid Hold-Out condition) is somewhat harder than learning that mid vowels trigger harmony. While there was only a trend between the Mid Hold-Out and the High Hold-Out conditions, there were no differences between the Mid Hold-Out and the Controls. This may be because of a combination of no generalization to New Vowels in the High Hold-Out condition and the fact that there was some memory for items explicitly given at training, making the differences between the two conditions harder to detect in a broad ANOVA. The fact that there were no differences between Old and New Stems or Old and New Vowel items in the Mid Hold-Out condition can be taken as evidence that there was minimal learning in the Mid Hold-Ou condition. This result supports the hypothesis that mid vowels are the best triggers for round vowels.

However, the fact that there was no effect of training for the Mid Hold-Out condition is surprising considering that there are no constraints against high vowels triggering vowel harmony, and that learning was generally robust in previous experiments for round harmony. One possibility may be the fact that the round alternation also involved a back alternation. Because the high front vowel ([i]) is typically resistant to triggering harmony (it is transparent in Finnish and Hungarian), learners may have been resistant to postulate a rule involving a back alternation where high front vowels can trigger harmony.

Another possibility for the overall reduced amount of harmonic responses in this experiment may arise from the fact that the training stimuli used two suffixes to induce the harmonic alternations. It may be that having one suffix alternation makes the harmonic pattern much easier to pick up on. Having a single suffix pattern points the learner exactly to what the alternation is and can then be able to form abstract rules from the simple alternation. With two suffix alternations, it becomes more difficult to narrow down what phonological process is taking place. With two suffix alternations, there are four suffix allomorphs (e.g., [mi], [mu], [gi] and [gu]). The learner has to place all four allomorphs with a triggering condition, which may be much harder than placing [mi] and [mu] with a triggering condition. The fact that the learning problem was much harder in this case may have made it harder to learn the less natural harmony condition (high vowel triggers).

Overall, the results of this experiment support the hypothesis that mid vowels are the most robust triggers for round harmony, supporting the use of a constraint that directly induces spreading of the feature round by mid vowels.

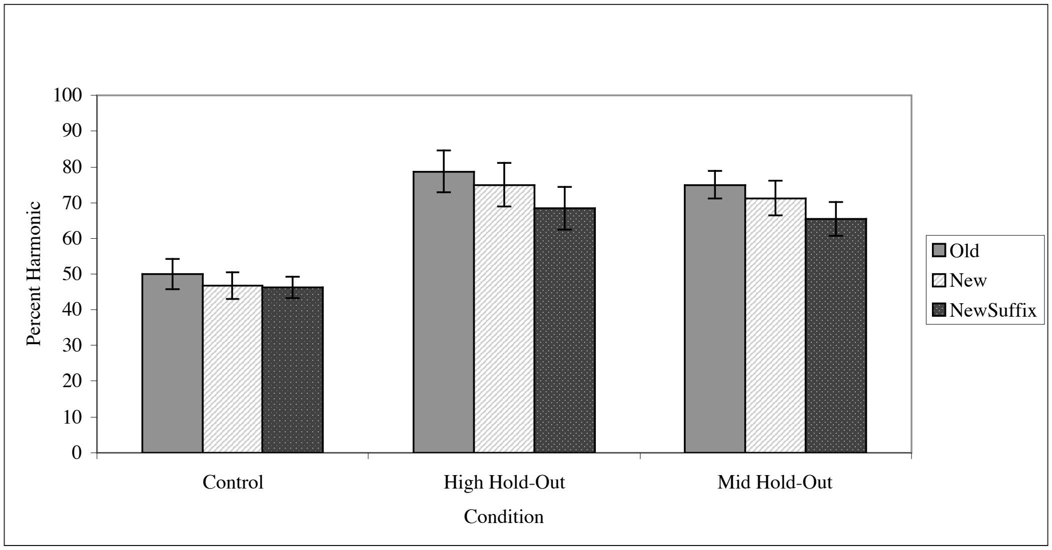
CONCLUSIONS

The experiments presented in this chapter addressed the nature of typological restrictions in learning biases. In Experiment 7, typological frequency of mid vowels undergoing round harmony was pitted against inventory constraints on round vowels. Because English speakers are able to accept [o] as a round counterpart to [e], there is no inventory restriction on mid vowels undergoing harmony. Participants were able to generalize to novel mid vowel suffixes despite the fact that fewer languages tolerate mid vowels undergoing harmony, as this restriction is due to constraints on vowel inventories rather than general learning constraints.

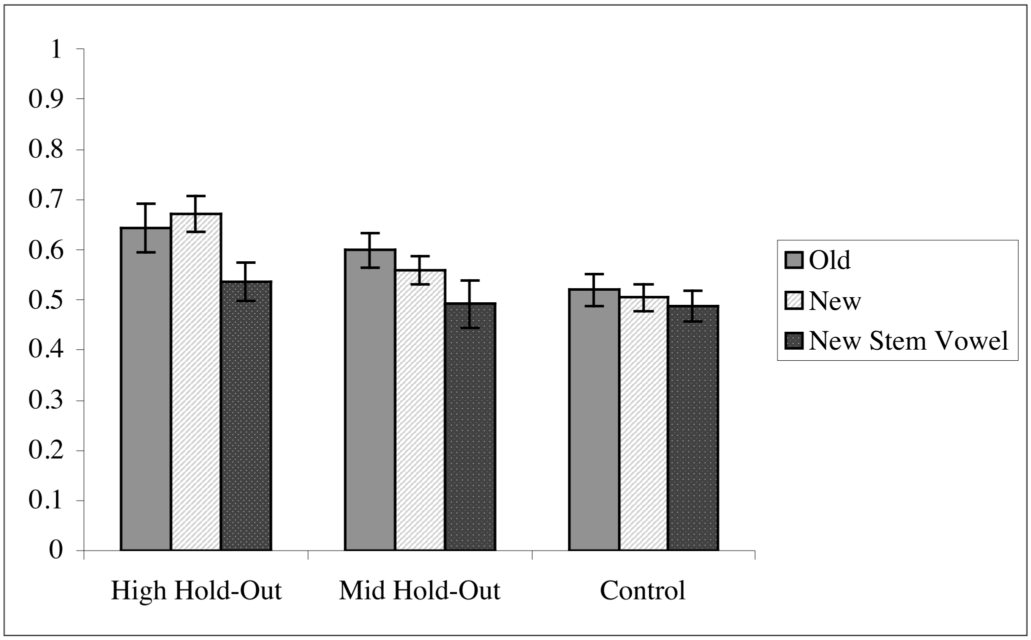
Experiment 8 supports the hypothesis that the robustness of mid vowels as harmony triggers emerges as a learning bias, a specific constraint on harmony triggers. Learners were able to infer a harmony pattern with only mid vowel triggers, but were unable to learn a harmony pattern with high vowel triggers, compared to the Control condition.

The results of Experiments 8 and 9 together support a theory of the typology of rounding harmony in which restrictions on harmony triggers must be based on specific constraints on what makes a good harmony trigger, while restrictions on harmony undergoers must be based on the inventory of the harmony language.

(177) Experiment 7 Results



(178) Experiment 8 Results



Appendix I: Experiment 7 Stimuli

Training
Stimuli
bimi
digi
gebe
gomo
kene
muto
nege
nopu
pidi
podo
punu
tudu
beme
buno
duku
kete
kogo
midi
mobo
mubu
niki
piki
tepe
tunu

New Stem
Items
budu
deke
dini
dutu
goto
kepe
mudu
mogo
nepe
pimi
tidi
tono

Appendix II: Experiment 8 Stimuli

Training

Mid Hold-Out	High Hold-Out	Suffix
kini	kene	mi/mu
migi	kepe	ge/go
pudu	kopo	ge/go
midi	mobo	ge/go
tunu	mogo	ge/go
mubu	moto	ge/go
niki	nege	mi/mu
tupu	nepe	ge/go
nupu	noto	ge/go
pimi	pete	mi/mu
bidi	beme	mi/mu
piki	podo	ge/go
punu	pomo	mi/mu
nipi	tede	mi/mu
tunu	tepe	ge/go
tudu	tono	mi/mu
bimi	bene	ge/go
bugu	bono	mi/mu
dimi	deke	mi/mu
tigi	dete	ge/go
dutu	dono	mi/mu
gipi	gebe	ge/go
guku	gomo	mi/mu
gunu	goto	mi/mu

Test Stimuli	Mid Hold-Out	Suffix	High Hold-Out	Suffix
New	budu	ge/go	goto	ge/go
New	nuku	ge/go	pete	ge/go
New	duku	mi/mu	tepe	mi/mu
New	kubu	ge/go	boto	ge/go
New	pidi	mi/mu	mogo	mi/mu
New	kipi-test	ge/go	pete	ge/go
New	nubu	ge/go	noto	ge/go
New	digi	mi/mu	kopo	mi/mu
New	tidi	mi/mu	deke	mi/mu
New	mutu	mi/mu	nepe	mi/mu
New	dini-test	ge/go	gobo	ge/go
New	nipi	mi/mu	tede	mi/mu
New Vowel	deke	ge/go	bidi	mi/mu
New Vowel	bene	mi/mu	bimi	ge/go

New Vowel	kogo	ge/go	bugu	mi/mu
New Vowel	gomo	mi/mu	dimi	mi/mu
New Vowel	gebe	ge/go	dutu	mi/mu
New Vowel	kene	mi/mu	gipi	ge/go
New Vowel	18noto	ge/go	tudu	mi/mu
New Vowel	dono	mi/mu	kini	mi/mu
New Vowel	dete	mi/mu	kubu	ge/go
New Vowel	bono	ge/go	midi	ge/go
New Vowel	beme	mi/mu	nupu	ge/go
New Vowel	mobo	ge/go	punu	ge/go
Old	bidi	mi/mu	kogo	ge/go
Old	bimi	ge/go	dono	mi/mu
Old	bugu	mi/mu	bodo	ge/go
Old	dimi	mi/mu	beme	mi/mu
Old	dutu	mi/mu	dete	ge/go
Old	gipi	ge/go	kene	mi/mu
Old	tudu	mi/mu	bene	ge/go
Old	kini	mi/mu	peke	mi/mu
Old	kubu	ge/go	bono	mi/mu
Old	midi	ge/go	mobo	ge/go
Old	nupu	ge/go	gomo	mi/mu
Old	punu	ge/go	gebe	ge/go

Chapter 11: Height Harmony Typology (Experiments 9-10)

The results of the experiments presented in Chapter 10 provide evidence that substantive biases for vowel harmony are not simply biases for the most frequently occurring phonological processes. Rather, biases are built out of phonetic and grammatical factors that shape the way languages are structured. In this chapter, the front/back asymmetry for height harmony languages is examined. In height harmony languages (e.g., Buchan Scots and several Bantu languages) there is an asymmetry between front vowels and back vowels such that front vowels are more likely to undergo harmony than back vowels (Hyman, 1999; Linebaugh & Cole, 2005). In Buchan Scots English, for example, height harmony applies between [-i] and [-e], but never between [-u] and [-o] (Paster, 2004).

The question that we address in this chapter is whether adult speakers of American English, who have no background in height harmony, are sensitive to front/back asymmetries in height harmony. Experiment 9 tests for this bias. English speakers are trained on height harmony language with either front suffixes or back suffixes, and are asked to generalize to novel suffixes. If learners are sensitive to the bias for front vowels to undergo harmony, learners should generalize to front vowels more readily than to back vowels.

Support for this bias is found in Experiment 9, in which learners generalized to front vowels, but not back vowels. Experiment 10 tests for further generalization in order to uncover the nature of the bias: grammatical or phonetic. If the bias is grammatical in nature, there should be a bias towards front vowels, even for front vowels whose height contrasts are perceptually weak such as [ɪ] and [ɛ]. However, if the bias is phonetic in nature, there should be generalization only to the height contrasts that are the most salient perceptually: [i] and [e], but not [ɪ] and [ɛ] or [u] and [o]. Our findings indicate that learners are biased to the most phonetically salient contrast ([i], [e]) rather than a pure bias to front vowels undergoing harmony, in that participants are unable to generalize to lax front vowels in a height harmony pattern.

EXPERIMENT 9

Experiment 9 tests for front/back asymmetries in learning a height harmony language by training participants on a height harmony language in which either front vowels undergo harmony (via the suffix alternation [-mi]/[-me]) or back vowels undergo harmony (via the suffix alternation [-mu]/[-mo]). If participants are biased towards front vowels undergoing harmony, we expect (i) a higher degree of learning for front vowels undergoing harmony and (ii) generalization to novel front vowel suffixes but no generalization to novel back vowel suffixes.

Method

Participants

All participants were adult native English speakers with no knowledge of a vowel harmony language. 61 Johns Hopkins undergraduate students participated for extra course credit and did not participate in any previous vowel harmony learning experiment. Participants were randomly assigned to one of three training groups: a Control group containing mixed harmony stems, a Front Vowel Suffix condition and a Back Vowel Suffix condition. Final analyses included 20 participants in each group. All participants were screened based on a perceptual (AXB) task. Those participants scoring less than 75 percent on this task were removed from the study. This occurred for one participant.

Design

The design of the experiment was identical to Experiments 6-7, except that participants in each hold-out condition were exposed to a height harmony alternation with either a front vowel suffix [-mi]/[-me] or a back vowel suffix [-mu]/[-mo]. Participants were tested on generalization to novel suffixes with a different front/back feature specification. The novel suffixes always contained a different vowel, and a different consonant. Participants were trained on either [-mi]/[-me] and [-gi]/[-ge] alternations, or [-gu]/[-go] and [-mu]/[-mo]. Training was counterbalanced such that half of the participants in each condition received [-mi]/[-me] and [-gu]/[-go] and the other half received [-gi]/[-ge] and [-mu]/[-mo]. Participants in the Control condition received disharmonic stems, and were also counterbalanced to receive identical test from the Front Hold-Out condition and the Back Hold-Out condition. Examples of training and test stimuli for Experiment 9 are shown in the tables in (179) and (180) below.

(179) Training Stimuli: Experiment 9

bemeg
dunig
getog
kubig
nugig
pikig
tudug

(180) Test Stimuli: Experiment 9

Test Items		Front Hold-Out Suffix	Back Hold-Out Suffix
Old	bimi	gu/go	gu/go
Old	doge	gu/go	gu/go
Old	gibu	gu/go	gu/go
New	nubu	gu/go	gi/ge
New	pete	gu/go	gi/ge
New	tidi	gu/go	gi/ge
NewSuffix	bipu	gi/ge	gi/ge
NewSuffix	diku	gi/ge	gi/ge
NewSuffix	nugi	gi/ge	gi/ge

The experiment finished with the same AXB perception task as in the previous experiments.

Stimuli

As mentioned above, the stimuli were of the same type as Experiments 6-7, with the exception that training consisted of two suffix vowel heights, and stems had one vowel height, depending on training.

Procedure

The procedure was identical to Experiments 6 and 7. Participants were given a break before beginning the AXB task after testing.

Results

Percent of harmonic responses were recorded for each subject for each of the training conditions. The mean responses for each test condition are presented in the figure, in (183) below.

Participants in the Control condition were compared to participants in each of the training conditions via a separate mixed design two-factor analysis of variance (ANOVA) with alpha set at $p = 0.05$. The between-subjects factor was Training, with two levels in each ANOVA: the Control group and each Hold-Out condition. Test Items (Old Stems, New Stems, New Suffix) was a within-subjects factor nested under the between-subjects factor Training. All conditions involved between-item comparisons.

For the ANOVA comparing Controls to the Front Hold-Out condition, there was no significant effect of Training (0.51 vs. 0.53, CI = 0.04; $F(1, 38) = 1.32$; $p > 0.05$), in that participants in the Front Hold-Out condition were more no more likely to choose the harmonic option than participants in the Control condition. There was no effect of Test Item ($F < 1$). There was an interaction ($F(2, 76) = 3.52$, $p < 0.05$).

For the ANOVA comparing Controls to Back Hold-Out, there was an effect of Training (0.51 vs. 0.58, CI = 0.06; $F(1, 38) = 5.02$, $p < 0.05$); participants in the Back Hold-Out condition were more likely to choose the harmonic candidate than participants in the Control condition. There was an effect of Test Item ($F(2, 76) = 9.36$ $p < 0.001$); there was an interaction ($F(2, 76) = 4.02$, $p < 0.05$).

For the ANOVA comparing Front Hold-Out to Back Hold-Out, there was a no effect of Training ($F(1, 38) = 1.95$, $p > 0.05$), no effect of Test Item ($F < 1$). There was an interaction ($F(2, 76) = 12.31$, $p < 0.001$).

To assess generalization, a t-test was performed comparing the New Suffix condition of the Control condition to the New Suffix condition for each training condition. There was no significant difference between New Suffix test items and Controls ($t < 1$) for the Back Hold-Out condition, but a significant effect of Training for the Front Hold-Out condition ($t(38) = 3.58$, $p < 0.01$) in that participants were as likely to select the harmonic choice for New Suffix test items as the Controls. These results suggest that participants generalized to front vowels but not back vowels.

Discussion

The results of Experiment 9 suggest that learners are able to learn a height harmony pattern, but only if the alternation takes place within front vowels. Participants were able to generalize to front vowels but not back vowels, and participants who were trained on back vowel suffix alternations were unable to form a generalization about the back vowel alternation, but were able to extend the pattern to the front vowel alternations. This suggests that learners are biased towards front vowel height alternations.

One curiosity about the results of this experimen is that learners exposed to back vowel suffixes showed no effect of training for Old and New Stem items, but an effect of training for novel suffix items. Learners showed higher harmonic performance on items that they were not trained on over the items that they were trained on. This is not due to a bias towards front vowels independent of learning, as this effect was not found in the control condition, even when the novel vowel was factored in. This suggests that learners in the Front Hold-Out condition learned a harmony rule that had a strong bias to apply to front vowels, but a weak bias to apply to back vowels, despite exposure to back vowels. This may be due to a prior constraint on front vowels undergoing harmony, or due to perceptual and attentional constraints that make applying the harmony rule to back vowels more difficult. The results also suggest that the results of a two-alternative forced-choice task can be fairly crude measurements of learning. Clearly there was an effect of training for novel vowels, despite a lack of effect in the Old and New Stem items. It may be that experiments that show no effect of training are simply not sensitive enough to see the effects of training, or that the right testing items have not been used to capture the learning effects.

The results of Experiment 9 support a learning bias towards front vowel height alternations such that learners exposed to front vowels undergoing harmony are more likely to show effects of training than learners exposed to back vowels undergoing height harmony. Further, learners do not seem to generalize from front vowels undergoing height harmony to back vowels, but learners do generalize from back vowels to front vowels. The two most likely possible explanations for this learning bias supported by the present experiment are that biases are biased in the grammar or that the biases are based in perception. The first possibility is that the featural representation for front vowels are more systematically linked to height features. For example, in English (as well as many other languages) there are more front vowels that contrast in height than back vowels, which means that height is more likely to be a relevant feature for front vowels than back vowels. However, this explanation seems unlikely, given that the majority of height harmony languages for which the front/back asymmetry is true have a 5-vowel inventory with only two sets of vowels with height contrasts (one front and one back). If it were only the number of height contrasts that drove the front/back asymmetry in a given language, the 5-vowel Bantu languages for which this asymmetry is most likely to hold do not fit the pattern. It is possible that front vowels are better equipped to handle height contrasts, which may lead to the asymmetry. However, to my knowledge, there is no theory of feature representation that differentiates the number of possible height contrasts for front and back vowels.

The second possibility is that the acoustics and perceptibility of front vowel height contrasts are larger than the perceptibility of back vowel height contrasts. In Experiment 9, participants were exposed to tense front vowels [i] and [e] which have the greatest perceptual and acoustic contrasts. However, front lax vowels [ɪ] and [ɛ] are perceptually and acoustically very similar, with a very weak contrast, particularly in English, such that some American English dialects lack this contrast (e.g., have no difference between pronunciations of *pin* and *pen*).

While the results of Experiment 9 may be due to differences in perception of height contrasts for front versus back vowels, we verified that the effects of generalization in Experiment 9 were not due to pure acoustic differences in F1 in the test stimuli for front versus back vowels, by comparing the F1 values for front and back vowels. High vowels had significantly lower F1 values for both front and back vowels ($F(1, 32) = 147.28$, $p < 0.001$) but there was no interaction ($F < 1$), indicating that the degree of F1 difference for high and mid vowels is the same for both front and back vowels. Because there was no significant effect of acoustics in the test stimuli, the explanation that acoustic differences in height for front and back vowels created the bias for front vowels undergoing harmony is only valid if this difference is couched in perception or a representation of the height of front and back vowels that is more stable than the differences (which were not statistically different) in the acoustic stimuli.

Experiment 10 explores the basis for the front/back asymmetry in height harmony found cross-linguistically as well as in Experiment 9. If learners are biased towards front vowel feature representations, they should be biased towards any front vowel contrast, even if that contrast is perceptually weak, as is the contrast for height found in front lax vowel height alternations. If learners are biased towards vowel contrasts that are highly perceptible and acoustically distinct, then they should fail to generalize to these lax vowel alternations. Experiment 10 tests this by testing for learning alternations of height harmony involving either lax vowels or back vowel stems.

EXPERIMENT 10

Cross-linguistically, height is a conditioning factor for back and round harmony (e.g., Turkish, Yawelmani), but the feature back is not a conditioning factor for height harmony (Clements, 1991; J. Cole & Trigo, 1988; van der Hulst & van de Weijer, 1995). Additionally, height harmony is often influenced by tenseness of the vowels, as high vowels tend to be tense, whereas non-high vowels tend to be lax (e.g., Menomoni) (J. Cole, 1991; J. Cole & Trigo, 1988; van der Hulst & van de Weijer, 1995).

Experiment 10 extends the poverty of the stimulus paradigm to height harmony. Participants were exposed to stems and affixed forms with either front vowels only [i, e, ɛ, ɪ] or tense vowels only [i, e, u, o]. Participants exposed only to front vowel forms saw back vowels in test only; participants exposed to tense vowel stems saw lax vowels in test only.

Method

Participants

All participants were adult native English speakers with no knowledge of a vowel harmony language and had not participated in vowel harmony learning experiments. 54 undergraduate students at Johns Hopkins participated for extra course credit. Participants were randomly assigned to one of three training groups: a Control group containing mixed harmony stems, a Lax Hold-Out condition and Back Hold-Out condition. Final analyses included 24 participants in each group. All participants were screened based on a perceptual (AXB) task. Those participants scoring less than 75 percent on this task were removed from the study; this occurred for five participants. One subject was dropped due to program error.

Design

The design of the experiment was the similar to Experiment 9, except instead of testing for generalizations in novel suffixes, we tested for generalizations to novel stem vowels. This decision was based on the fact that there was no effect of training in the test for back vowel suffixes. To create the greatest possibility for participants to learn a harmony rule, the height alternation was made using front vowels, as the results of Experiment 9 indicate that learners are more likely to learn a height harmony pattern in which front vowels undergo harmony. Experiment 10 makes use of Lax Hold-Out and Back Hold-Out conditions. In addition, the experiment included a simple AXB perception task for vowel contrasts that included lax vowel alternations. The task was designed as a way to screen participants for perception of high and mid contrasts in English. Examples of training and test stimuli are provided in the tables in (181) and (182) below.

(181) Training Stimuli: Experiment 10

Back Hold-Out	Lax Hold-Out
mɛte	doge
dɪgi	duni
piki	piki
gibɪ	diku
kɪtɪ	punu
beme	beme
tedɛ	teko
mepe	mepe

(182) Test Items: Experiment 10

Back Hold-Out		
Old	**New**	**New Vowel**
mɛte	gɛme	punu
dɪgi	mɪbi	tudu
piki	kipi	mubu
Lax Hold-Out		
Old	**New**	**New Vowel**
bimi	tidi	pɛnɛ
punu	nubu	bɛdɛ
gomo	mogo	gɛbɛ

Stimuli

The stimuli were of the same type as Experiment 9, with the exception that the stimuli included lax vowels and the suffix alternation was [-mi]/[-me] for all critical training conditions.

Procedure

The procedure was identical to Experiment 9.

Results

Percent of harmonic responses were recorded for each subject for each of the training conditions. The mean responses for each test condition are presented in Figure (184), below.

Participants in the Control condition were compared to participants in each of the training conditions via a separate mixed design two-factor analysis of variance (ANOVA) with alpha set at $p = 0.05$. The between-subjects factor was Training, with two levels in each ANOVA: the Control group and each Hold-Out condition. Test Items (Old Stems, New Stems, New Vowel) was a within-subjects factor nested under the between-subjects factor Training. All conditions involved between-item comparisons.

For the ANOVA comparing Controls to the Back Hold-Out condition, there was a significant effect of Training (0.49 vs. 0.54, *CI*= 0.04; $F(1,46)=6.64$; $p< 0.05$), in that participants in the Back Hold-Out condition were more likely to choose the harmonic option than participants in the Control condition. There was no effect of Test Item ($F(2,92) = 2.04$, $p > 0.05$), and no interaction ($F < 1$).

For the ANOVA comparing Controls to Lax Hold-Out, there was a significant effect of Training ($F(1, 46) = 17.53$, $p < 0.001$); participants in the Lax Hold-Out condition were more likely to choose the harmonic candidate than participants in the Control condition. There was no effect of Test Item (0.49 vs. 0.58, *CI*=0.04; $F(2, 92) = 2.35$, $p > 0.05$) and there was no interaction ($F(2, 92) = 1.13$, $p > 0.05$).

For the ANOVA comparing Lax Hold-Out to Back Hold-Out, there were no effects for Training ($F(1, 46) = 1.92$, $p > 0.05$). There was an effect of Test Item ($F(2, 92) = 4.94$, $p < 0.05$), and no interaction ($F < 1$).

To assess generalization, contrasts were made within each condition comparing New Stems test items to New Vowel test items. For the Lax Hold-Out condition, there was a marginal difference between New Stems and New Vowel (0.59 vs. 0.52, CI = 0.07; $F(1, 23) = 3.53$, $p < 0.08$). For the Back Hold-Out condition, there were no differences between the New Stems and New Vowel test items (0.56 vs. 0.49, *CI* = 0.09; $F(1, 23) = 1.94$, $p > 0.05$).

To further assess generalization, a t-test was performed comparing the New Vowel items of the Control condition to the new vowels for each training condition. There was no difference between New Vowel test items and Controls ($t = 1.42$, $p > .05$) for the Lax Hold-Out condition or the Back Hold-Out condition ($t = < 1$).

Discussion

Participants in Experiment 10 learned a height harmony language in which either tense vowels only or front vowels only triggered harmony (to front tense vowels). Learners displayed no generalization for either lax vowels or back vowels. This is the result we expect if learners only generalize to vowels that are perceptually very distinct. Front tense vowels are perceptually distinct for height contrasts but back vowels and front lax vowels are perceptually weaker for height contrasts. If learners are biased against positing a harmony rule with vowels that are perceptually weak, then it is expected that learners should not generalize to perceptually weak back vowels or lax front vowels. These results suggest that the bias for front vowels undergoing harmony is due not to a bias for front vowels participating in harmony, but is based on the perceptual properties of the height contrast for front tense vowels.

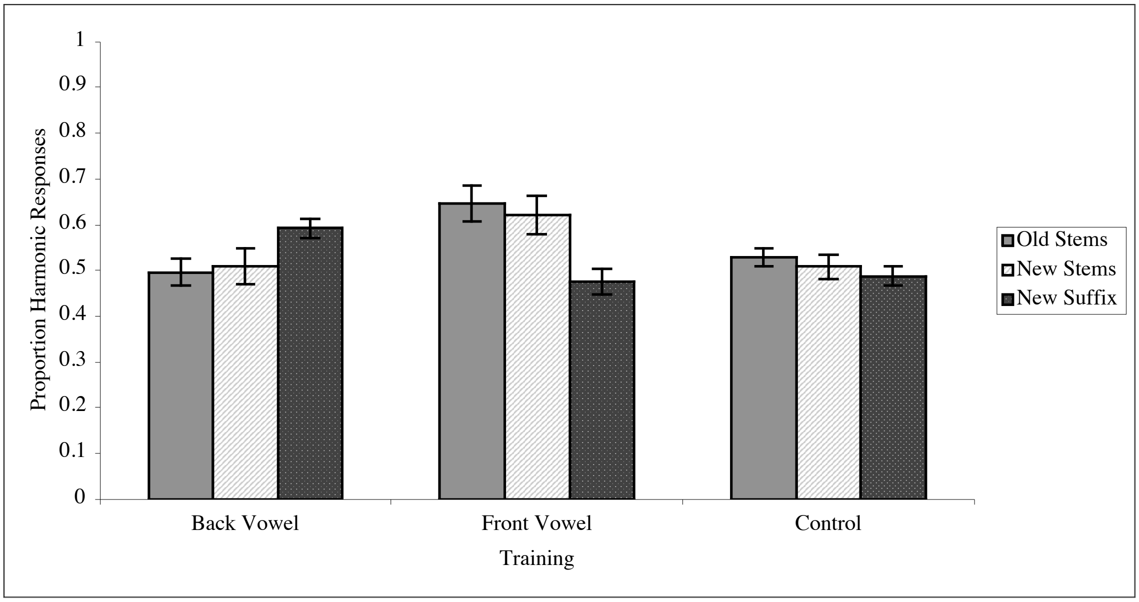
One possible interpretation of these findings is that rather than using featural knowledge of vowel contrasts, learners use an interpolation strategy such that learners will include all contrasts within their training items. For example, if the weakest contrast in the training item was the front lax contrast, then learner should infer that any contrast greater than or equal to the front lax contrast will be acceptable in the rule. However, if this were the strategy that learners adopted, then it should be expected that learners would have generalized to back vowels, as the back vowel contrast is greater than the lax vowel contrast (English speakers are more likely to collapse [ɪ] and[ɛ] than [u] and [o], given that the lax contrast has collapsed in many dialects). However, learners did not generalize to back vowels, suggesting that learners are not simply using the acoustic distance of the high-mid contrasts to decide which vowels fit the harmony generalizations.

The results of Experiment 9 and 10 are much less robust in terms of proportion of harmonic responses. This may be due to the fact that of all the vowel height contrasts that were tested, only one is perceptually salient. It may be that learners are biased to form harmony patterns that make use of the most perceptually salient vowels. This is a different strategy than the one posed by Kaun (1995, 2004), in which the perceptually weakest vowels initiate spreading in order to preserve contrasts. This fact may be particular to rounding contrasts as the actual effect of rounding is difficult to hear on front vowels. In the case of height, the actual height of the vowel is not at issue, rather it is the perceptibility of the high/non-high counterpart.

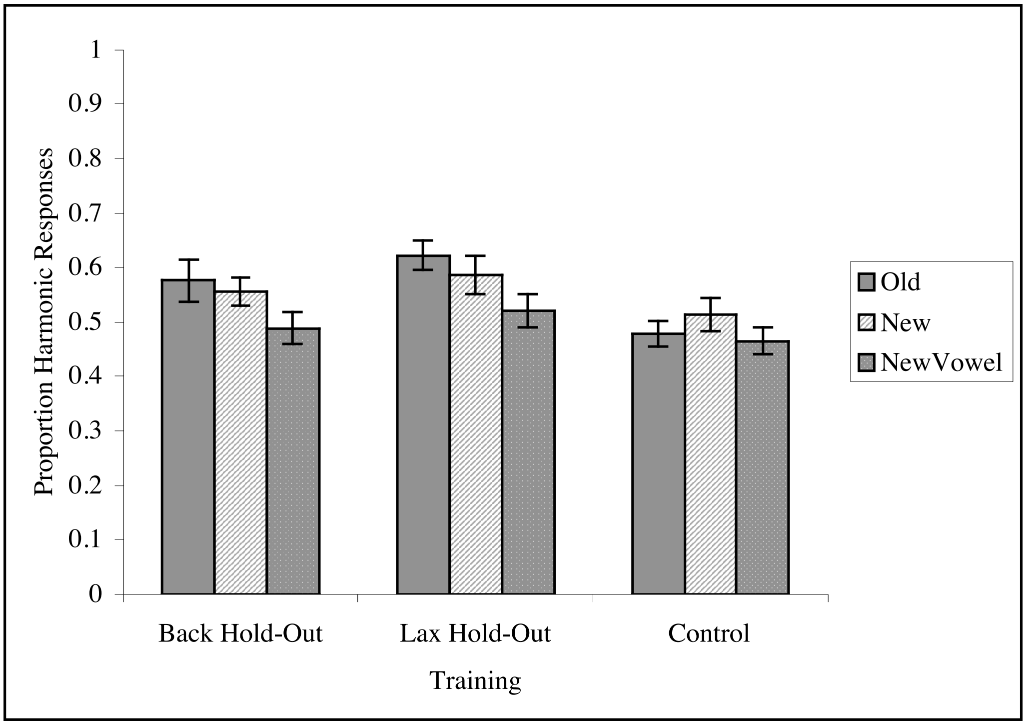
Conclusion

Experiments 9 and 10 demonstrate substantive biases for height harmony languages. Experiment 9 indicated that learners are biased towards front vowels undergoing vowel harmony over back vowels. Experiment 10 confirmed that the results of Experiment 9 were not due to a bias towards all front vowels participating in vowel harmony, as participants failed to generalize to perceptually weak lax vowels. Rather, these results suggest that learners are biased to form patterns that are based on perceptually strong contrasts, such as the front, tense vowel contrast [-mi]/[-me].

(183) Experiment 9 Results



(184) Experiment 10 Results



Appendix I: Experiment 9 Stimuli

Training
bemeg
bimig
bipug
dikug
dogeg
dunig
getog
gibug
gomog
keteg
koteg
kubig
mepeg
midig
mubug
negog
nopeg
nugig
pikig
podog
punug
tekog
tonog
tudug

Test Items		Front Hold-Out Suffix	Back Hold-Out Suffix
Old/NewSuff	bimi	gu/go	gu/go
Old/NewSuff	doge	gu/go	gu/go
Old/NewSuff	gibu	gu/go	gu/go
Old/NewSuff	gomo	gu/go	gu/go
Old/NewSuff	kete	gu/go	gu/go
Old/NewSuff	kubi	gu/go	gu/go
Old/NewSuff	mepe	gu/go	gu/go
Old/NewSuff	nego	gu/go	gu/go
Old/NewSuff	piki	gu/go	gu/go
Old/NewSuff	punu	gu/go	gu/go
Old/NewSuff	tono	gu/go	gu/go
Old/NewSuff	tudu	gu/go	gu/go
New	bimu	gu/go	gi/ge
New	deke	gu/go	gi/ge

New	dutu	gu/go	gi/ge
New	gone	gu/go	gi/ge
New	kopo	gu/go	gi/ge
New	kipi	gu/go	gi/ge
New	kugi	gu/go	gi/ge
New	mogo	gu/go	gi/ge
New	nebo	gu/go	gi/ge
New	nubu	gu/go	gi/ge
New	pete	gu/go	gi/ge
New	tidi	gu/go	gi/ge
NewSuff/Old	bemeg	gi/ge	gi/ge
NewSuff/Old	bipug	gi/ge	gi/ge
NewSuff/Old	dikug	gi/ge	gi/ge
NewSuff/Old	dunig	gi/ge	gi/ge
NewSuff/Old	getog	gi/ge	gi/ge
NewSuff/Old	koteg	gi/ge	gi/ge
NewSuff/Old	midig	gi/ge	gi/ge
NewSuff/Old	mubug	gi/ge	gi/ge
NewSuff/Old	nopeg	gi/ge	gi/ge
NewSuff/Old	nugig	gi/ge	gi/ge
NewSuff/Old	podog	gi/ge	gi/ge
NewSuff/Old	tekog	gi/ge	gi/ge

Appendix II: Experiment 10 Stimuli

Training Items

Back Gen	Lax Gen
mɛte	doge
dɪgi	duni
piki	piki
gibɪ	diku
kɪtɪ	punu
beme	beme
tedɛ	teko
bɛnɛ	podo
dɛbe	nope
pIdi	nugi
bimi	bimi
kinɪ	gibu
nɪgɪ	tudu
kete	kete
dekɛ	nego
nɛgɛ	tono
nɛke	kote
tɪbi	kubi
midi	midi
tipɪ	bipu
gɪmɪ	mubu
mepe	mepe
genɛ	geto
pɛdɛ	gomo

Test Items:
Back Gen

Old	New	New Vowel
mɛte	gɛme	punu
dɪgim	mɪbi	tudu
piki	kipi	mubu
gibɪm	kinɪ	nubu
nɪgɪm	bɪgɪm	dutu
mepe	pete	budu

tedɛ	bepɛ	podo
bɛnɛ	dɛkɛ	gomo
kete	deke	tono
bimi	tidi	mobo
gɪmɪ	nɪgɪ	kopo
nɛgɛ	gɛtɛ	mogo

Test Items:
Lax Gen

Old	New	New Vowel
doge	gone	kɪtɪ
kubi	kugim	nɪgɪ
piki	kipi	gɪmɪ
gibu	bimu	bɪkɪ
tudu	dutu	nɪkɪ
mepe	pete	tɪpɪ
nego	nebo	tɛbɛ
tono	kopo	dɛgɛ
kete	deke	mɛkɛ
bimi	tidi	pɛnɛ
punu	nubu	bɛdɛ
gomo	mogo	gɛbɛ

Chapter 12: Directionality (Experiments 11-12)[14]

Directionality was an important aspect of the theoretical portion of the dissertation presented in Chapter 4. In the experiments presented here, we test whether learners are biased towards left-to-right harmony, right-to-left harmony or bidirectional harmony. In this experiment, we trained participants on a round harmony language with either a prefix or a suffix. At test, participants will be tested on generalization to items with a prefix or a suffix. If participants encode directionality in their rule learning, they should fail to generalize to both prefixes and suffixes. If learners encode bi-directionality in their learning, they should generalize to both prefixes and suffixes. If learners are biased towards left to right harmony (as many languages appear to be), then learners should generalize to suffixes but not prefixes.

Using results from two experiments using the artificial grammar learning paradigm, we argue that vowel harmony is non-directional by default and that the right-to-left biases found within the typology of vowel harmony may best be thought of in terms of a bias against prefix harmony triggers.

Directionality has been an important issue within the theoretical discussion of vowel harmony because in many cases the same vowel harmony process can be described either directionally (e.g., from left-to-right) or non-directionally (e.g., stem-outward). For example, vowel harmony in Turkish appears to apply from left-to-right. However, because Turkish is a suffixing-only language, harmony can also be described in terms of a non-directional stem-outward harmony system. For most harmony languages, both interpretations may be descriptively adequate, but they make different predictions about

[14] This is a modified version of (Finley & Badecker, in press-b)

what learners actually infer given ambiguous data. Therefore, the default nature of directionality could be either directional or non-directional (e.g., morphological). In the directional description, a vowel feature spreads in one direction from a designated source vowel (e.g., the rightmost vowel of the morphological stem) to a target vowel. In the non-directional description, the vowel feature spreads outward from the source vowel, regardless of the direction of spreading, so the vowel feature may spread from right-to-left, left-to-right, or both depending on the location of potential harmony undergoers.

The default nature of directionality (e.g., directional versus non-directional) in vowel harmony is still debated, as there are several empirical reasons to posit both directionality and non-directionality as the default. Directional descriptions are desirable for explaining the large number of languages that seem to only have harmony in one particular direction (e.g., Turkish, Finnish, Hungarian, Assamese). Within these languages, there appears to be an asymmetry between right-to-left harmony and left-to-right harmony, namely a bias towards right-to-left harmony (Hyman, 2002b). For example, languages such as Karajá (Ribeiro, 2002), Assamese and Pulaar (Mahanta, 2007) involve harmony from suffixes to stems (right-to-left), but not from prefixes to stems (left-to-right). Within the set of languages in which affix vowels may trigger harmony, there are cases where suffixes, but not prefixes spread to stems, (e.g., Turkana, (Noske, 1990, 2000)), but no languages where prefixes, but not suffixes spread to stems (Bakovic, 2000; Krämer, 2003). In other words, prefix triggers imply suffix triggers. For example, Kalenjin has prefix triggers, but the majority of harmony triggers are suffix triggers (Hyman 2002). This lack of harmony from prefixes to stems suggests a directional description of harmony with a right-to-left bias. Further, related spreading processes such as consonant harmony (Hansson, 2001) and tonal spreading (Chen, 2000) are typically characterized in terms of specific directions.

However, there is also evidence in favor of a non-directional description of vowel harmony. First, it is possible to explain the default directionality of many harmony languages in terms of the morphology (Bakovic 2000), as in suffixing-only languages like Turkish and Hungarian. Secondly, there are many cases of dominant-recessive vowel harmony in which the presence of a particular feature value (e.g., [+ATR]) will induce spreading in both directions throughout the lexical item. These types of languages (e.g., Kalenjin, Nez Perce, Lango, Mayak) are best described non-directionally, because the dominant feature value spreads from stem to suffix and vice versa. It is the location of the feature value that drives spreading, rather than intrinsic directionality.

Because there is evidence in favor of both directional and non-directional descriptions of vowel harmony, other methods for exploring the default nature of directionality must be employed. To this end, we present data from two artificial grammar learning experiments that test for the default nature of directionality in vowel harmony. The artificial grammar learning paradigm is a promising approach for testing the nature of grammatical defaults. Many researchers (Finley & Badecker, 2008; Moreton, in press; Pycha et al., 2003; Wilson, 2003b, 2006) have had success in training participants in novel languages, as well as testing particular details of linguistic theory. For example, the Poverty of the Stimulus Method (Wilson, 2006) makes use of generalization to novel items in order to infer substantive learning strategies. Finley and Badecker (in preparation) (see Experiment 9) trained participants on a stem-to-suffix height harmony rule with front vowel suffixes (e.g., [-mi]/[-me]; [bidi, bidimi]; [godo, godome]) or back vowel suffixes (e.g., [-mu]/[-mo]; [bidi bidimu]; [godo godomo]), and tested on both. They showed generalization to cross-linguistically preferred front vowel suffixes, but no generalization to dispreferred back vowel suffixes. Differential generalization of this sort provides evidence of learning biases, and can therefore shed light on the nature of default grammatical processes.

What makes the Poverty of the Stimulus Method so useful in testing learning biases is that the training data are designed to be ambiguous with regard to the generalization that they embody. For example, training with examples of height harmony with suffixes that only contain front vowels (e.g., [bidu bidu-gi], [bedo, bedo-ge]) is compatible with a harmony pattern that applies only to front vowels, as well as more general harmony pattern that applies to all vowels. The test data are disambiguating (contain front and back vowel suffixes) and thereby allow one to assess the nature of the generalization that the learners adopt (e.g., a harmony rule that applies to front vowels or a harmony rule that applies to both front and back vowels). This method allows the researcher to ask questions about learners' natural inferences on phonological processes. Here we use the Poverty of the Stimulus Method to test the default nature of directionality in vowel harmony. By exposing participants to prefixing-only or suffixing-only data during training, it is possible to test learners' generalization to novel affixes and therefore test generalization to a novel direction. If participants, exposed only to stems spreading to suffixes in a left-to-right harmony, infer a directional rule, they should not generalize to right-to-left harmony in novel prefixes. However, if the learner infers a non-directional rule (e.g., stem-outward), they should generalize to novel prefixes. By exposing the inferences that learners make when presented with a limited data set, the test data can inform us about the nature of directionality in vowel harmony.

Design

In Experiment 11, we expose participants to a stem-outward harmony training data with either prefixes only or suffixes only and then test generalization to the withheld (novel) affix type. Experiment 12 takes the same approach, but with affix-triggering harmony, where suffixes spread to stems or prefixes spread to stems. From this ambiguous training data, participants can either infer a strictly directional process, or a morphologically controlled non-directional process. Generalization to novel affix classes (e.g., prefixes if only trained on suffixes) suggests that the learner has inferred a non-directional harmony pattern.

For the experiments presented here, we ask two main questions. In Experiment 11, these questions are asked in reference to stem-outward harmony. In Experiment 12, these questions are asked in reference to affix-triggering harmony.

(185) What is the default nature of directionality in vowel harmony?

Regardless of the default nature of directionality in vowel harmony, it is possible for learners to prefer one direction over another. For example, an affix-driven harmony may prefer suffixes spreading to stems over stems spreading to suffixes. Because the typological data suggests a right-to-left preference in vowel harmony, we ask (186):

(186) Is there a right-to-left preference for vowel harmony?

These questions may be addressed through the behavior of our participants on items that target generalization of the harmony pattern to novel suffixes at test. If participants generalize vowel harmony both from suffixes to prefixes, and prefixes to suffixes, it suggests that they inferred a non-directional harmony pattern, and, crucially, that these participants are biased to learn non-directional harmony. If participants do not generalize to either novel prefixes or to novel suffixes, it suggests that they are biased to learn a strictly directional harmony pattern. If participants have a right-to-left bias for vowel harmony, learners should generalize asymmetrically; they should generalize to prefixes only in stem-controlled harmony, and to suffixes only in affix-triggering harmony.

Another measure of the right-to-left bias for harmony comes from the robustness of learning and generalization to prefixing and suffixing languages. For stem-controlled harmony, if participants show greater harmonic responses to prefixes than to suffixes, it suggests a right-to-left bias for harmony. For affix-triggering harmony, suggestion of a right-to-left bias is present if participants show greater learning for suffix harmony triggers (right-to-left) than prefix harmony triggers (left-to-right). Further, a right-to-left bias for harmony could be demonstrated if participants show greater generalization to novel stems than to either novel suffixes (in stem-controlled harmony) or novel prefixes (in prefix-triggering harmony).

In both experiments, participants in the critical conditions were exposed to a back/round harmony language. In this language, all lexical items contained either only front/unround vowels [i, e] or only back/round vowels [o, u]. All training items contained a harmonic two-syllable stem (stress on the initial syllable), followed by its concatenated form (prefixed or suffixed). Affixes were counterbalanced such that half of the participants heard an affix with a bilabial nasal at training ([mi]/[mu]) and a velar stop for novel affixes ([gi]/[gu]), and the other half tested on the opposite. For example, a participant trained on the prefix [mi-]/[mu-] would be tested on the suffix [-gi]/[-gu].

Stimuli lists for both Experiment 11 and 12 are provided in the appendix. Examples of training stimuli for Experiment 11 are in the table in (187) below.

(187) Training Stimuli: Experiment 11

Prefix Training	**Suffix Training**	**Control**
beme mi-beme digi mi-digi gomo mu-gomo nupu mu-nupu	beme beme-mi digi digi-mi gomo gomo-mu nupu nupu-mu	beme tipo digi kino gomo kote nupu gome

All participants were given a simple AXB perception task for English vowels. In this perception task, participants were given three isolated syllables. Participants were asked to indicate whether the second vowel was identical to the vowel in the first syllable (e.g., [bi pi ku]) or to the vowel in the third (e.g., [bi pu ku]). The task was used as a screening to ensure that all participants were able to discriminate isolated English vowels. If participants scored less than 70% on this task, the data from the test phase was discarded. No participants in Experiment 11 failed this task.

Experiment 11

Experiment 11 tests for the default nature of directionality of vowel harmony in stem-controlled harmony systems. We exposed participants to a back/round stem-controlled harmony pattern with either prefixes only or suffixes only. Test items included both prefixed and suffixed items in all conditions. Generalization to novel affix classes suggests a learning bias towards a non-directional harmony pattern.

Participants:

48 adult native English speakers from the Johns Hopkins University community participated in Experiment 1. No participants had prior knowledge of a vowel harmony language, and none had participated in previous vowel harmony learning experiments. Participants were either paid $7 or given extra course credit for their participation.

Method:

The experiment consisted of three phases: a training phase, a testing phase and the AXB perception phase, all run on a Macintosh computer using Psyscope (Cohen et al., 1993). Participants were given verbal instructions at the start of the experiment, and written instructions at the start of each phase. Before the training phase, participants were told that they would be listening to a language that they had never heard before, and that they should pay attention to how the language sounds, but need not memorize the words they hear. Participants were given no information about morphology or vowel harmony, nor were they given any feedback during the test.

There were three between-subject conditions in the training phase: Prefix Training, Suffix Training and Control conditions. Prefix Training participants were exposed to stems followed by prefixed items, Suffix Training participants were exposed to stems followed by suffixed items and Controls were exposed to a mixture of harmonic and disharmonic stems. The training phase for the critical training conditions consisted of 24 stem and stem+affix pairs repeated 5 times each in random order. Each bare stem (e.g., [bidi]) was followed by its affixed form with a 500 ms delay (e.g., [bidi, bidi-mi] for Suffix Training, [bidi, mi-bidi] for Prefix Training).

The Control condition was designed to ensure that all results were due to learning rather than a particular bias in the stimuli or in English for a particular response independent of training. We exposed participants to both harmonic and disharmonic stems to give participants some exposure to the training set without providing the opportunity for these participants to make any inferences about a harmony (or disharmony) pattern in the data.

The test phase consisted of 36 forced-choice test item pairs. One item in the pair was harmonic, the other was disharmonic (e.g., [bidi-mi, *bidi-mu]). Items were counterbalanced for order of harmonic response and round versus unround affixes. There were three within-subject conditions in the test set that varied by training condition: Old Stems/Old Affix, New Stems/Old Affix and Old Stems/New Affix. The Old Stems/Old Affix condition contained items that were identical to the training set. The New Stems/Old Affix condition contained items that had the same affix as in the training set, but a novel stem. These items were used to test for abstract learning of the directional harmony pattern. The Old Stems/New Affix condition contained stems that were heard in the training set, but affixes that were held-out. This was to test for generalization to novel affixes and the default nature of directionality in vowel harmony. Half of the participants in the Control condition heard test items identical to those in the Suffix Training condition, and the other half heard test items identical to those in the Prefix Training condition. The task concluded with the AXB perception task described above. Examples of test items for Experiment 11 are provided in the table in (188) below.

(188) Test Items: Experiment 11

	Old Stems/Old Affix	**New Stems/Old Affix**	**Old Stems/New Affix**
Prefix Training	mi-beme *mu-beme mi-digi *mu-digi mu-gomo *mi-gomo	mi-tede *mu-tede mu-bugu *mi-bugu mu-pogo *mi-pogo	beme-gi *beme-gu digi-gi *digi-gu gomo-gu *gomo-gi
Suffix Training	beme-mi *beme-mu digi-mi *digi-mu gomo-mu *gomo-mu	tede-mi *tede-mu bugu-mu *bugu-mi pogo-mu *pogo-mi	gi-beme *gu-beme gi-digi *gu-digi gu-gomo *gi-gomo

<u>Results:</u>

Results of Experiment 11 are reported in the figure in (191) below in terms of mean proportion harmonic responses. Each test condition is reported separately. To test the overall effect of training, we compared each training condition to the Control condition separately with a 2 x 3 mixed design ANOVA. The ANOVA comparing the Suffix Training condition to the Control condition showed a significant effect of Training (0.77 vs. 0.51, $CI = 0.11$; $F(1, 30) = 29.11$, $p < 0.001$), but no significant effect of Test Item ($F(2, 60) = 1.03$, $p > 0.05$). The results show that there was a significant effect of Training on the Suffix Training condition; participants learned the harmony pattern. The ANOVA comparing the Prefix Training condition to the Control showed a significant effect of Training (0.73 vs. 0.51, $CI = 0.10$; $F(1,30) = 18.36$, $p < 0.001$), but no effect of Test Item ($F(2,60) = 1.34$, $p > 0.05$). These results suggest that overall, participants learned the harmony pattern.

To assess the level of generalization to novel affixes, we compared the means of the Old Stem/New Affix Test Condition and the Control in each of the Training Conditions. There was a reliable difference for both novel suffixes (the New Affix condition for the Prefix Training Condition) ($t(30)=2.10$, $p < 0.05$) and novel prefixes (the New Affix condition for the Suffix Training Condition) ($t(30)=2.10$, $p < 0.05$). In both of these conditions, the mean harmonic responses differed significantly from Control participants. This suggests that learners inferred a non-directional, morphologically controlled (e.g., stem-outward) rule; both training conditions generalized to novel affixes.

To assess the robustness of generalization for novel affixes, we compared the means of the New Affix and New Stem test conditions for the Prefix and Suffix Training Conditions combined. There was a significant effect of Test Item ($F(1,30)=12.20$, $p < 0.01$), suggesting that generalization to novel stems was more robust than generalization to novel affixes. There was no effect of Training ($F < 1$), and no interaction between the New Stem and the New Affix conditions ($F < 1$), suggesting no preference for novel prefixes over novel suffixes. These results demonstrate an effect of directionality, in that generalization to a novel direction is less robust than generalization to novel stems.

These results indicate significant effects of Training over all three conditions of test items, as well as the New Affix condition for both Prefix Training and Suffix Training conditions. This generalization to novel affixes for novel prefixes as well as for novel suffixes suggests that participants inferred a non-directional harmony pattern.

Discussion

The results of Experiment 11 provide evidence for non-directionality in vowel harmony, in that participants were able to generalize to novel affixes. However, participants were more likely to prefer harmonic items for novel stems than harmonic items in a novel direction. This may be because learners infer the harmony rule based on the morphological alternations (e.g., [-mi]/[-mu]) that they are exposed to, and perceive novel stems with old affixes as closer to the exemplar used for training than old stems with a novel affix. This finding is consistent with previous results in which participants were less likely to choose the harmonic response for items with a novel suffix vowel than items with a novel stem vowel (but the same suffix vowel) (Finley and Badecker 2008) (see Experiments 6 and 7). Generalizing to a novel affix, especially a novel class of affixes (prefix to suffix and vice versa) is more difficult than generalizing to a novel stem.

One possible interpretation of these results is that the selection of harmonic affixes in the New Affix conditions actually reflects a harmony rule with absolute directionality in which the novel affixes trigger spreading to a novel stem. For example, if a learner selects the harmonic item [mi-bidi], it is because they are following a left-to-right harmony rule in which the initial vowel spreads its features to the stem. If participants learned a directional rule in which affixes could spread to stems, they may still select the harmonic option in the forced-choice test. However, the design of the experiment and test items provides little reason to believe that this is the strategy that learners took. First, participants were only exposed to harmonic alternations in which an affix alternated between two different allomorphs. There is little reason to suspect that learners inferred a harmony pattern in which affixes spread to stems. Second, all test items differed only in terms of the vowel quality of the affix (e.g., [mi]/[mu]). Therefore, it is implied in the test items that it is the affix that undergoes harmony. Further, because participants were familiarized with all stems in the New Affix condition, it is unlikely that learners would infer that the affix vowel was the harmony trigger.

These results provide little support for a right-to-left bias for stem-outward harmony. First, participants generalized to both prefixes and suffixes, and there was no significant difference between the rate of generalization to prefixes and suffixes. Typologically, this result is not surprising. The right-to-left biases for vowel harmony are seen in affix-dominant harmony, not stem-controlled harmony. For example, languages that have right-to-left harmony only (e.g., Assamese, Pulaar) are all affix-dominant harmony systems. Second, the right-to-left bias found in harmony may be due to a bias against prefix triggers for harmony, as the only known cases of languages where prefixes spread harmony also allow suffixes to spread harmony. Therefore, a true test of the right-to-left bias for vowel harmony would be found using affix-triggering harmony.

Experiment 12:

Experiment 12 uses the same methodology as Experiment 11, but with an affix-triggering harmony language, to assess the default nature of directionality in vowel harmony, and the right-to-left bias for harmony found cross-linguistically.

Participants:

38 adult native speakers of English participated in Experiment 12 for extra course credit. No participant participated in Experiment 11 or a previous harmony experiment. Two participants were dropped due to a failure meet threshold (70%) on the AXB perception task, for a total of 36 participants used in the data analysis (12 participants in each training condition).

Method

The procedure for Experiment 12 was identical to Experiment 11, with some minor changes reflecting the fact that Experiment 12 involved training participants on an affix triggered harmony pattern. Suffixes/prefixes spread to stems, rather than spreading from the stem to an affix. In order to present participants with alternations, all stems were unround in their bare form, and all affixes were round. Participants heard a bare unround stem followed by its concatenated round form (e.g., [bidi, mu-budu], [bidi, budu-mu]). Examples of training stimuli are provided in the table in (189) below.

(189) Training Stimuli: Experiment 12

Prefix Training	**Suffix Training**	**Control**
beme mu-bomo kene mu-kono midi mu-mudu pidi mu-pudu	beme bomo-mu kene kono-mu midi mudu-mu pidi pudu-mu	beme bumi kene kino midi nego pidi podi

As in Experiment 11, there were three training conditions: Prefix Training, Suffix Training and Control. The Prefix Training condition heard prefix harmony triggers (e.g., [bidi, mubudu]). Participants in the Suffix Training condition heard suffix harmony triggers (e.g., [bidi budumu]). The Control condition heard a mixture of harmonic and disharmonic stems (e.g., [bidi, pegu]). The forced choice test items reflected the fact that alternations took place in the stem rather than the affix. The affix always contained a round vowel, but the stem alternated between round and unround (e.g., [bidi-mu, budu-mu], [mu-bidi, mu-budu]). Test items were of the same three conditions as Experiment 11: Old Stems/Old Affix (which were items that appeared in the training set), New Stems/ Old Affix (which were items that had the same affix as training but novel stems) and Old Stem/New Affix (which were items that contained a novel affix) and were used to test for generalization to a novel affix. Examples of test stimuli for Experiment 12 are provided in the table in (190) below.

(190) Test Stimuli: Experiment 12

Prefix Training	**Suffix Training**
Old Stems/Old Affix	**Old Stems/Old Affix**
*kene-mu kono-mu	*gu-kene gu-kono
*pidi-mu pudu-mu	*gu-pidi gu-pudu
New Stems/Old Affix	**New Stems/Old Affix**
dono-mu *dene-mu	gu-dono *gu-dene
bugu-mu *bigi-mu	gu-bugu *gu-bigi
Old Stems/New Affix	**Old Stem/New Affix**
*gu-kene gu-kono	*kene-mu kono-mu
*gu-pidi gu-pudu	*pidi-mu pudu-mu

The experiment concluded with the same AXB perception task as Experiment 1, used as a screening to ensure that all could perceive the training and test stimuli. Two participants failed this task, and their learning data was discarded.

Results

Results of Experiment 12 are reported in the figure in (192) below in terms of mean proportion harmonic responses. Each test condition is reported separately. To test the overall effect of training, we compared each training condition to the Control condition separately with a 2 x 3 mixed design ANOVA. The ANOVA comparing the Suffix Training condition to the Control condition showed a significant effect of Training (0.75 vs. 0.54, *CI* = 0.14; $F(1, 22) = 10.2$, $p < 0.05$), but no effect of Test Item ($F(2,44) = 1.03$, $p > 0.05$). These results indicate that participants successfully learned the harmony pattern. The ANOVA comparing the Prefix Training condition to the Control showed no effect of Training (0.57 vs. 0.54, *CI* = 0.12; $F<1$), no significant effect of Test item, and a significant interaction between factors ($F(2,44) = 5.09$, $p < 0.05$). This indicates that participants did not learn the harmony pattern in the Suffix Training condition.

To assess the level of generalization to novel affixes, we compared the means of the Old Stem/New Affix Test condition to the Control conditions in each of the Training conditions. Novel prefixes (the New Affix condition for the Prefix Training Condition) were significantly different from the Control Condition ($t(22)=2.10$, $p < 0.05$). There was a marginal effect of Training in the Novel Affix condition of the Prefix Training condition, but in the opposite direction. There were slightly fewer harmonic responses to novel affixes (suffixes) than controls ($t(22)=2.0$; $p = 0.06$). These results suggest that if one is able to learn a harmony rule, then that harmony rule will be non-directional by default.

We compared the Prefix Training condition to the Suffix condition to test whether learning or generalization was more robust in either condition, using the same mixed-design ANOVA as above. There was a significant effect of Training ($F(1,22) = 6.4$, $p < 0.05$) and no significant interaction ($F(2, 44) = 2.0$, $p > 0.05$). These results suggest that learning was more robust for the Suffix Training condition than the Prefix Training Condition. There was a significant effect of Test Item ($F(2,44) = 4.30$, $p < 0.05$); there was an overall significant difference between New Stems and New Affix ($F(2, 44) = 10.37$ $p < 0.01$). This result supports a right-to-left bias for vowel harmony in the sense that participants seemed biased against learning a harmony pattern with only prefix triggers.

In order to ensure that the null effect of training in the Prefix Training condition was not due to the fact that there were fewer harmony responses for New Affix, we compared the Prefix Training condition with the Control condition for just New Stems and Old Stems/Old Affix test conditions. There was no main effect for this ANOVA ($F(1, 22) = 1.89$, $p > 0.05$), no effect of Test item ($F < 1$), and no interaction ($F < 1$). We also compared the Prefix Training condition to 50% chance. There was also no significant effect of Training ($F(1, 22) = 2.01$, $p > 0.05$). These results suggest that participants in the Prefix Training condition did not learn the harmony pattern.

Discussion

The results of Experiment 12 are consistent with the results of Experiment 11: participants generalized to novel affixes if they learned the harmony pattern. Participants in Experiment 12 were unable to learn the harmony pattern with prefix harmony triggers. This indicates that our learners were biased against prefix-triggering harmony, notably, this bias is found cross-linguistically: the few known languages that allow prefix harmony triggers predominantly allow suffix harmony triggers. This is consistent with our findings that learners only generalize to novel prefix triggers from suffix harmony triggers.

GENERAL DISCUSSION

The experiments presented in this chapter addressed two questions concerning the representation of vowel harmony: is vowel harmony directional by default? And is there a right-to-left bias for vowel harmony? The results of our experiments support a non-directional default for harmony, and a right-to-left bias for directional harmony. However, this right-to-left bias manifests itself as a bias against prefix harmony triggers.

Stem controlled harmony is non-directional by default, and there is little evidence for a right-to-left bias for stem-controlled harmony. Affix-triggering harmony appears to be more complex. Suffix-triggering harmony is learnable, while prefix-triggering harmony is not learnable within the short training period that we provided for our participants. However, suffix-triggering harmony does seem to imply a general, non-directional affix-triggering harmony pattern, as learners exposed to suffix triggers also accepted prefix harmony triggers. It appears that prefix triggers are acceptable only in the presence of suffix harmony triggers, a finding consistent with cross-linguistic patterns. However, training on prefix harmony triggers is not enough to induce acceptability of suffix harmony triggers. This right-to-left bias in affix triggering harmony may arise from co-articulatory pressures (Ohala, 1994). Vowel-to-vowel co-articulation is typically from right-to-left. Further, there is evidence that in some modes of speech, speech errors are most often regressive (right-to-left) (Fromkin, 1973).

One potential cause for the difficulty that participants had in learning the prefix trigger harmony pattern is the fact that the stress was on the first syllable in the stimulus items. While all vowels were clearly articulated and had at least secondary stress (to avoid vowel reduction), the main stress was always on the initial syllable. For prefixed items, the primary stress shifted from the stem to the prefix, which may have made parsing the prefixed item more difficult than parsing the suffixed item. However, if learning failure arose from parsing errors, then we should expect (1) difficulty in learning for stem-controlled prefixed forms and (2) no generalization to novel prefix harmony triggers. However, we found both robust learning of prefixed forms for stem-controlled harmony as well as robust generalization to novel prefixed forms. There must be something that made the prefix triggering harmony pattern difficult to learn beyond the stress placement.

Implications for a Theory of Vowel Harmony

The experimental evidence that vowel harmony is non-directional by default has important consequences for a theory of vowel harmony. Within Optimality Theory (Prince and Smolensky 1993/2004), our results support a set of constraints and representations that predict a typology of vowel harmony languages that show a bias for non-directionality and against prefix harmony triggers.

One possibility for predicting a bias against prefix harmony triggers may come from a constraint against prefixes as the source of harmony. Within Headed-Feature Domains Theory (Smolensky 2006) and Span Theory (McCarthy 2004), the source for spreading is represented as a head in the spreading domain. Because prefixes tend to be phonologically weak in that they are more likely to undergo processes than to trigger them, a constraint that penalizes spreading domains in which a prefix is the source or head is a worthwhile option to pursue further.

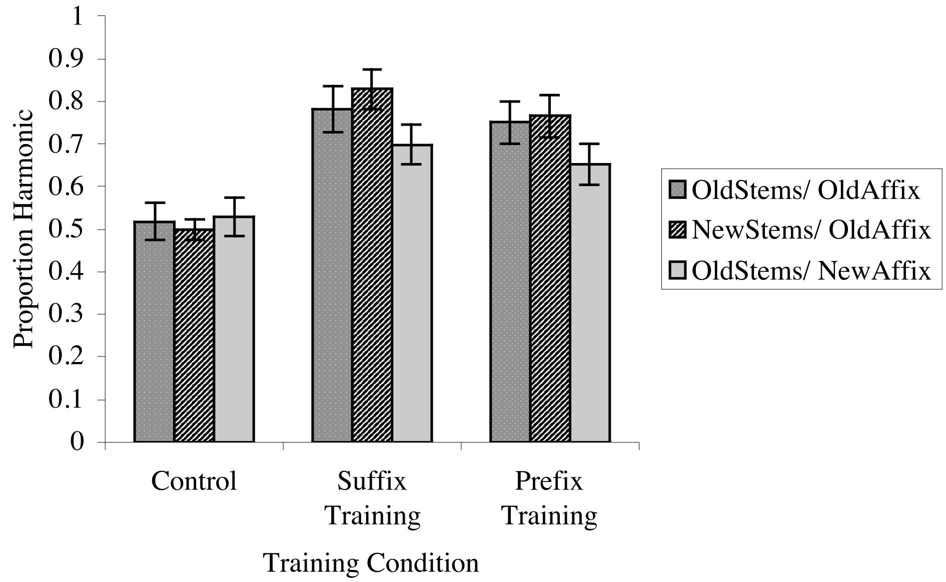
To account for the results of Experiment 12 in Turbid Spreading, we must assume the following constraints: ID[F], SPREAD-Affix, *SPREAD-Prefix as well as standard SPREAD constraints. SPREAD-Affix induces spreading from the affix to the stem, while *SPREAD-Prefix penalizes spreading from the prefix. At the initial state (the adult English speaker), we assume that ID[F] ranks above all spreading-inducing constraints and that SPREAD-Affix is ranked below *SPREAD-Prefix. In order to learn that affixes spread harmony, they must rank ID below SPREAD-Affix. Because *SPREAD-Prefix is already ranked lower than ID, the ranking SPREAD-Affix above ID will imply that SPREAD-Affix is also ranked above *SPREAD-Prefix and that all affixes, prefixes and suffixes spread. After being exposed to suffixes undergoing harmony, learners infer a rule that applies to both prefixes and suffixes. However, when learners are exposed to prefixes triggering harmony, they are exposed to data that goes against the constraint *SPREAD-Prefix, and their reaction may be to lower the ranking of this constraint *SPREAD-Prefix. However, lowering the ranking of *SPREAD-Prefix does nothing to induce spreading of affixes. Only raising the SPREAD-Affix constraint ranking can do this. Exposure to data that is typologically implausible may cause incorrect re-ranking strategies that will decrease ease of leanring. This account explains why it is that exposure to suffixes spreading can induce spreading in prefixes, despite the fact that exposure to prefixes only decreases the learning rate.

There are several possibilities for deriving the default non-directional nature of vowel harmony. One approach is that is compatible with Turbid Spreading (Chapter 4) to use inherently directional constraints such as in Turbid Spreading, but with a restriction on the initial state in learning that would induce a non-directional harmony when training data is ambiguous between directional and bi-directional vowel harmony. For example, if SPREAD-R and SPREAD-L were, at the initial state, paired together with no ranking between the two constraints, then as faithfulness moves to a lower-ranked position, it will move below both SPREAD-R and SPREAD-L unless there is evidence of a specific ranking between the two constraints. One advantage of this approach is that it directly encodes the results of the experiment as a learning bias, leaving open the possibility for languages with a specific direction for spreading. However, more research is needed to differentiate between these different formalizations of the non-directional bias for vowel harmony.

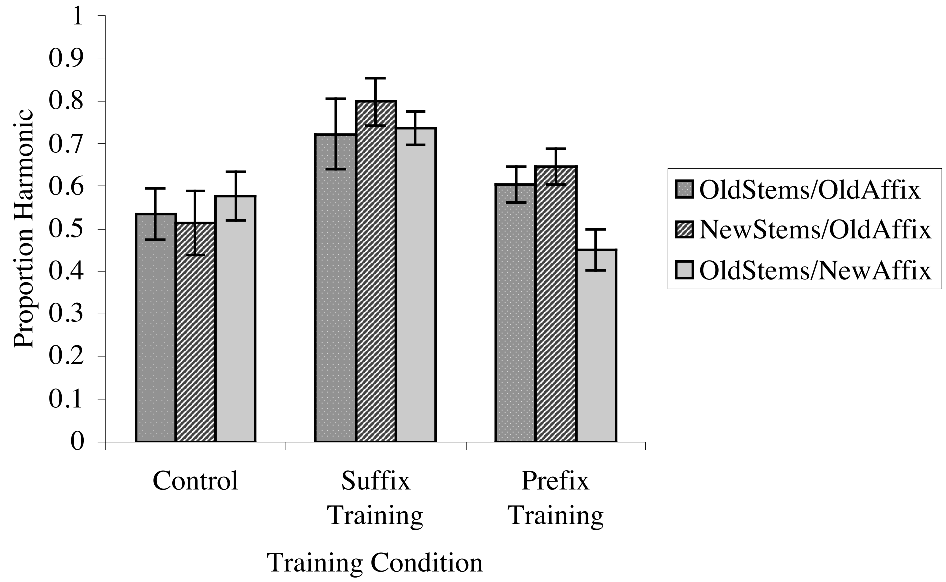
The experiments presented in this chapter support the notion of a right-to-left bias for vowel harmony as a bias against prefix harmony triggers, as well as the non-directional nature of vowel harmony.

This work also represents the benefits of an interaction of experimental and theoretical methodologies. Theoretical considerations created the need for the experiments in this paper. The results of our experiments create new issues for theoretical phonology: how to represent the default nature of directionality in vowel harmony, and the bias against prefix harmony triggers. Future work will continue in this vein, continuously integrating theoretical and experimental methodologies to better understand the nature of phonological representations.

(191) Experiment 11 Results



(192) Experiment 12 Results



Appendix I: Experiment 11 Stimuli

Training
beme
bono
biki
digi
duku
gebe
gomo
goto
bimi
kene
kete
kogo
midi
mobo
mubu
nupu
nege
niki
pidi
podo
punu
tudu
tunu
tepe

Test Items	mi-Prefix	mi-Suffix	gi-Prefix	gi-Suffix
beme	Old	Old	mi-S	Mi-P
bono	Old	Old	mi-S	Mi-P
digi	Old	Old	mi-S	Mi-P
duku	Old	Old	mi-S	Mi-P
gebe	Old	Old	mi-S	Mi-P
gomo	Old	Old	mi-S	Mi-P
kene	Old	Old	mi-S	Mi-P
midi	Old	Old	mi-S	Mi-P
mobo	Old	Old	mi-S	Mi-P
nupu	Old	Old	mi-S	Mi-P
pidi	Old	Old	mi-S	Mi-P
tudu	Old	Old	mi-S	Mi-P
dono	New	New	New	New
bugu	New	New	New	New

bigi	New	New	New	New
gede	New	New	New	New
gobo	New	New	New	New
pogo	New	New	New	New
mutu	New	New	New	New
nipi	New	New	New	New
nuku	New	New	New	New
peke	New	New	New	New
kidi	New	New	New	New
tede	New	New	New	New
biki	gi-S	gi-P	Old	Old
dimi	gi-S	gi-P	Old	Old
goto	gi-S	gi-P	Old	Old
kete	gi-S	gi-P	Old	Old
kogo	gi-S	gi-P	Old	Old
mubu	gi-S	gi-P	Old	Old
nege	gi-S	gi-P	Old	Old
niki	gi-S	gi-P	Old	Old
podo	gi-S	gi-P	Old	Old
punu	gi-S	gi-P	Old	Old
tepe	gi-S	gi-P	Old	Old
tunu	gi-S	gi-P	Old	Old

Appendix II: Experiment 12 Stimuli

Training Items

beme
bono
biki
digi
duku
gebe
gomo
goto
dimi
kene
kete
kogo
midi
mobo
mubu
nupu
nege
niki
pidi
podo
punu
tudu
tunu
tepe

New Stem Test Items

gobo
tede
dono
pogo
bugu
nipi
mutu
kidi
peke
bigi
nuku
gede

Chapter 13: Conclusion

This dissertation is a comprehensive collection of theoretical and experimental work on the nature of vowel harmony. I have argued that the problem of over-predicting vowel harmony typologies can be solved using the Turbid Spreading representational approach to vowel harmony which enhances previous work on turbid representations in phonology. Using computations over finite-state grammars, it was possible to compute a complete typology of vowel harmony interactions, including interactions of vowel harmony and epenthesis. Particularly, this typology contains only attested patterns and none of the previously cited pathological grammars. Experimental evidence for the need for avoiding harmony pathologies comes from artificial grammar learning experiments that train adult native English speakers on vowel harmony languages with a single morpho-phonemic alternation (e.g., [bede bede-mi]; [bopo bopo-mu]). Experiments 1 and 2 suggest that learners are biased towards directional harmony over 'majority rules' harmony (an unattested language where the direction of spreading is determined by the number of vowel features in the input). Experiment 3 provided a basis for testing biases in non-participating vowels.

Further experiments suggests that adult learners of vowel harmony are biased towards the same grammars that are cross-linguistically common or 'unmarked'. We hypothesize that the emergence of cross-linguistic typologies is shaped largely by learning biases. Experiments 4-5 provided evidence for feature-based representations in phonological processes in terms of generalization to novel vowels. Experiment 6 provided evidence for the generality of vowel harmony processes showing generalization to novel morphemes. Experiments 7 and 8 provided evidence for the constraints on triggers and targets in rounding harmony; high vowels are preferred harmony undergoers as a result of language-specific inventory constraints, but mid vowels are preferred harmony triggers from substantive biases on the nature of triggers for vowel harmony. Experiments 9 and 10 provided evidence that the cross-linguistic bias for front vowels to undergo height harmony over back vowels is due to learning biases as opposed to phonetic differences between front and back vowel contrasts. Experiments 11 and 12 suggest that learners are biased towards bi-directional stem-outward and dominant-recessive harmony but not left-to-right affix-driven harmony. These learning biases may explain why dominant-recessive harmony is typically bi-directional, but that there are no languages with prefixes that trigger spreading of a vowel feature to the stem.

The results of the theoretical, experimental and computational analyses in this dissertation demonstrate the complexity of vowel harmony interactions in the cross-linguistic typology. The hypothesis is that the main restrictions on the typology for phonological processes arise out of biases in the learner, and that these biases are present in adult speakers of English.

13.1 Future Research

While the research presented in this dissertation has shed light on a number of questions regarding the nature of representations in Optimality Theory and the nature of learning biases in adult learners, there are still several unanswered, and many novel questions that arise from the work presented here.

13.1.1 Theoretical Extensions

As argued in Chapter 4, the theory of Turbid Spreading shows promise for a larger research program in understanding the typology of vowel harmony and how it interacts with other phonological processes. Several open issues need to be addressed to further this research program, including understanding the nature of vowel deletion and other phonological processes, as well as understanding the nature of the interaction between constraints forcing dominant-recessive vowel harmony and directional SPREAD constraints.

The Turbid Spreading analysis of vowel harmony presented in Chapter 4 deals mainly with 'toy,' ideal examples of vowel harmony. An important contribution of the theory would be to show that turbid representations are able to account for additional idiosyncracies that are specific to particular harmony languages such as stress dependency, domain restrictions and differential behavior of non-participating vowels (e.g., when some non-participating vowels trigger [+F] while others trigger [–F]).

While the typology of harmony presented in Chapter 5 indicated that the Turbid Spreading analysis avoids myopia violations with respect to epenthesis, it does not account for the fact there are languages with stress-dependent harmony (the stressed vowel is always the harmony trigger) but no languages with harmony-dependent stress (e.g., a language whose stress patterns were dependent on which vowels undergo harmony). One possibility for explaining these facts using Turbidity Theory would be to design the representation of the stressed vowel and the representation of the vowel features such that vowel stress can affect vowel features but vowel features cannot affect vowel stress.

Another aspect of the theory of turbid representations that needs to be explored further is whether there is independent evidence for epenthesizing non-participating epenthetic vowels at the pronunciation level and participating epenthetic vowels at the projection level. This dichotomy predicts that epenthetic vowels should behave differently with respect to other processes depending on whether they are epenthesized at the projection or pronunciation level. Future work will need to verify or falsify this prediction.

Further, the non-participation of epenthetic vowels to abstract phonological processes was governed by the SPREAD constraints. However, not all phonological processes involve this constraint, as in stress assignment. For example, if epenthetic vowels are transparent to stress, it would have to be governed by some other constraint (presumably on stress). Future work will address transparency of epenthetic vowels to other phonological processes independent of spreading.

13.1.2 Computational Extensions

The computational analysis of the typology of vowel harmony for Turbid Spreading was successful in predicting an accurate typology of vowel harmony systems. However, there are several refinements that could be made to the finite-state machines. First, the use of directionally evaluated constraints is done in an ad-hoc manner such that the machine can only account for strings of a finite length, and the machines get increasingly more complicated with each additional vowel. Future work will seek to implement directionally evaluated constraints in a way that makes it possible to evaluate strings of unbounded length, and will decrease the complexity of the machines, as was done in Eisner's (2000) work.

While the dissertation presented artificial grammar learning data, there was no computational learning simulations for the proposed theory. Future work will explore how the finite-state machine grammar could be learned. Specifically, I would like to make use of the maximum entropy model for learning phonotactic constraints (Hayes & Wilson, to appear).

13.1.3 Experimental Extensions

The experiments presented in this dissertation can be further extended in a variety of ways. A hypothesis supported by the experiments reported in this dissertation is that the biases that learners show in the experiments are the same learning biases that cause cross-linguistic typologies. However, all of the experiments were performed on adult speakers of English. Our hypothesis predicts that we should find the same biases in infants, young children and speakers of other languages. Future work will test this prediction using different populations to test learning biases for vowel harmony languages.

As mentioned in the experimental chapters, there are several possible follow-up studies to understand the nature of learning biases. For example, replicating Experiments 1 and 2 (majority rules versus directional spreading) on non-linguistic stimuli will provide information about the linguistic nature of the learning biases found in these experiments. Because no effect of training was found in Experiment 3, it is important to replicate this experiment to understand what makes it possible to learn about the behavior of non-participating vowels in an artificial grammar learning setting.

13.1.4 Extensions Beyond Vowel Harmony

The work presented here has focused solely on the typology of vowel harmony processes. However, there are many other phonological processes that show complex cross-linguistic typologies, such as tone, stress and syllable structure (to name a few). Future work will take a similar approach to exploring additional phonological process, in order to better understand the nature of typology and learning biases on a broader scale.

13.2 Conclusions

The work presented in this dissertation provides an interdisciplinary approach to the study of phonological processes, specifically vowel harmony. I have argued that a representational approach to vowel harmony in Optimality Theory is able to avoid pathological predictions while making appropriate predictions for the typology of vowel harmony, such as transparency and opacity. Such a representational approach can be transformed into finite-state machines so that the predicted typology may be analyzed computationally. Experiments using the artificial grammar learning paradigm provided evidence that the typology of harmony languages found in the literature arises from learning biases.

The work presented in this dissertation represents some of the beginnings for truly integrating theoretical, computational and experimental techniques for studying phonological processes. Given the many ways that this research can be extended, there is much hope that the methods used in this dissertation can be applied elsewhere to further our understanding of the language faculty.

References:

Abu-Salim. (1987). Vowel harmony in Palestinian Arabic: a metrical perspective. *Journal of Linguistics, 23*, 1-24.

Akinlabi, A. (1993). Underspecification and the phonology of Yoruba /r/. *Linguistic Inquiry, 24*, 139-160.

Akinlabi, A. (1996). Featural affixation. *JL, 32*, 239-289.

Alderete, J. (1999). *Morphologically governed accent in Optimality Theory*. UMass, Amherst.

Andersen, T. (1999a). Consonant alternation and verbal morphology in Mayak (Northern Burun). *Afrika und Uberse, 82*, 65-97.

Andersen, T. (1999b). Vowel harmony and vowel alternation in Mayak (Western Nilotic). *Studies in African Linguistics, 28*(1), 1-29.

Anderson, S. (1981). Why phonology isn't "natural". *Linguistic Inquiry, 12*, 493-547.

Aoki, H. (1968). Nez Perce vowel harmony and Proto-Sahaptian vowels. *Language, 42*, 759-767.

Archangeli, D., & Pulleyblank, D. (1994). *Grounded Phonology*. Cambridge: MA: The MIT Press.

Archangeli, D., & Pulleyblank, D. (2002). Kinande vowel harmony: domains, grounded conditions and one-sided alignment. *Phonology, 19*, 139-188.

Aslin, R. N., Saffran, J. R., & Newport, E. (1997). Computation of conditional probability statistics by 8-month-old infants. *Psychological Science, 9*, 321-324.

Bakovic, E. (1999). Assimilation to the unmarked. *Penn Working Papers in Linguistics, 6*(1).

Bakovic, E. (2000). *Harmony, dominance and control*. Unpublished doctoral dissertation, Rutgers University.

Bakovic, E. (2005a). Antigemination, assimilation and the determination of identity. *Phonology, 22*, 279-315.

Bakovic, E. (2005b). *Phonological opacity and the counterfactual derivation*.Unpublished manuscript, ROA-777.

Bakovic, E. (2005c). Vowel harmony and stem identity. *Lingua, 2*, 77-132.

Bakovic, E. (2006a). *Cross-derivational feeding, globality, and opacity*.Unpublished manuscript, ROA.

Bakovic, E. (2006b). *A note on overapplication opacity*.Unpublished manuscript.

Bakovic, E., & Wilson, C. (2000). Transparency, strict locality and targeted constraints. *WCCFL, 19*, 43-56.

Batibo, H. (1996). Loanword clusters nativization rules in Tswana and Swahili: A comparative study. *South African Journal of African Languages, 16*.

Beckman, J. M. (1998). *Positional faithfulness*. UMass Amherst.

Beckman, J. N. (1997). Positional faithfulness, positional neutralisation and Shona vowel harmony. *Phonology, 14*, 1-46.

Best, C. T., & McRoberts, G. W. (2003). Infant perception of non-native consonant contrasts that adults assimilate in different ways. *Language and Speech, 46*, 183-216.

Blumenfeld, L. (2006). *Constraints on phonological interactions*. Stanford University.

Boersma, P. (1999). On the need for a separate perception grammar.

Boersma, P., & Hayes, B. (2001). Empirical tests of the gradual learning algorithm. *Linguistic Inquiry, 32*, 45-86.

Boersma, P., & Levelt, C. (1999). *Gradual constraint-ranking learning algorithm predicts acquisition order*. Paper presented at the 30th Child Language Research Forum.

Boersma, P., & Weenink. (2005). Praat: Doing phonetics by computer.

Bonatti, L. L., Pena, M., Nespor, M., & Mehler, J. (2005). Linguistic constraints on statistical computations: The role of consonants and vowels in continuous speech. *Psychological Science, 16*, 451-459.

Booij, G. (1984). Neutral vowels and the autosegmental analysis of Hungarian vowel harmony. *Linguistics, 22*, 629-641.

Brasington, R. W. P. (in preparation). *Vowel epenthesis in Renellese and its general implications*.Unpublished manuscript, University of Reading, UK.

Brentari, D. (1998). *A prosodic model of sign language phonology*. Cambridge, MA: MIT Press.

Brown, R., & McNeill, D. (1966). The "tip-of-the-tongue" phenomenon. *Journal of Verbal Learning and Verbal Behavior, 5*, 325-337.

Carpenter, A. (2005). Acquisition of a natural vs. and unnatural stress system. In A. Brugos, M. R. Clark-Cotton & S. Ha (Eds.), *BUCLD 29 Proceedings* (pp. 134-143). Somerville, MA: Cascadilla Press.

Chambers, K. E., Onishi, K. H., & Fisher, C. (2003). Infants learn phonotactic regularities from brief auditory experience. *Cognition, 87*, B69-B77.

Charette, M., & Goksel, A. (1998). Licensing constraints and vowel harmony in Turkic languages. *Structure and interpretation: Studies in phonology, 4*(65-88).

Chen, M. (2000). *Tone sandhi: Patterns across Chinese dialects*. Cambridge: Cambridge University Press.

Chen-Main, J. (2007). Targeted constraint Optimality Theory and overlapping violations. In L. Bateman, M. O'Keefe, E. Reilly & A. Werle (Eds.), *Papers in Optimality Theory III* (pp. 21-40). Amherst, MA: GLSA.

Chomsky, N. (1965). *Aspects of a theory of syntax*. Cambridge: MIT Press.

Chomsky, N., & Halle, M. (1968). *The sound pattern of English*. New York, NY: Harper & Row.

Christophe, A., Peperkamp, S., Pallier, C., Block, E., & Mehler, J. (2004). Phonological phrase boundaries constrain lexical access I. Adult data. *Journal of Memory and Language, 51*, 523-547.

Clements, G. N. (1976). The autosegmental treatment of vowel harmony. *Phonologica*, 111-119.

Clements, G. N. (1977). Neutral vowels in Hungarian vowel harmony: an autosegmental interpretation. *NELS, 7*, 49-64.

Clements, G. N. (1985). The geometry of phonological features. *Phonology Yearbook, 2*, 225-252.

Clements, G. N. (1991). Vowel height assimilation in the Bantu languages. *Berkeley Linguistics Society, 17*, 25-64.

Clements, G. N., & Sezer, E. (1982). Vowel and consonant disharmony in Turkish. In v. d. H. a. Smith (Ed.), *The structure of Phonological Representations* (Vol. II, pp. 213-255). Dordrecht: Foris.

Cohen, J. D., MacWhinney, B., Flatt, M., & Provost, J. (1993). PsyScope: A new graphic interactive environment for designing psychology experiments. *Behavioral Research Methods, Instruments and Computers, 25*, 257-271.

Cole, J. (1991). *Planar phonology and morphology*. New York: Garland Publishing, Inc.

Cole, J., & Kisseberth, C. (1994). An optimal domains theory of harmony. *Studies in Linguistic Sciences, 24*, 1-13.

Cole, J., & Trigo, L. (1988). Parasitic harmony. In N. Smith & H. van der Hulst (Eds.), *Features, segmental structures and harmony processes* (pp. 19-38). Dordrecht: Foris.

Cole, R. A. (1973). Listening for mispronunciations: a measure of what we hear during speech. *Perception and Psychophysics, 11*, 153-156.

Conway, C. M., & Christiansen, M. H. (2006). Statistical learning within and between modalities. *Psychological Science, 17*(10), 905-911.

Conway, C. M., & Pisoni, D. B. (2007). Links between implicit learning of sequential patterns and spoken language processing. *Cognitive Science Society Proceedings*.

Creider, C., & Rottland, F. (1997). Noun classification in Southern Nilotic: Datooga. *Afrika und Ubersee, 80*, 71-93.

Curtin, S., Mintz, T. H., & Christiansen, M. H. (2005). Stress changes the representational landscape: Evidence from word segmentation. *Cognition, 96*, 233-262.

Davidson, L., Smolensky, P., & Jusczyk, P. (2004). The initial and final states: Theoretical implications and experimental explorations of richness of the base. In R. Kager, J. Pater & W. Zonnefeld (Eds.), *Constraints in phonological acquisition* (pp. 321-368). Cambridge: Cambridge Unversity Press.

Dimmendaal, G. J. (2002). Constraining disharmony in Nilotic: What does and optimal system look like? *Journal of African Language and Linguistics, 23*, 153-181.

Dupoux, E., Kakehi, K., Hirose, Y., Pallier, C., & Mehler, J. (1999). Epenthetic vowels in Japanese: A perceptual illusion? *Journal of Experimental Psychology: General, 25*, 1568-1578.

Dyck, C. (1995). Pasiego pretonic metaphony revisited. *Toronto Working Papers in Linguistics*, 21-53.

Eisner, J. (2000). *Directional constraint evaluation in Optimality Theory*. Paper presented at the 35th Annual Meeting for the Association for Computational Linguistics and the 8th Conference of the European Association for Computational Linguistics, Madrid, July.

Erdal, M. (2004). *A grammar of Old Turkic*. Leiden: Brill.

Fikkert, P. (2005). Learning in Optimality Theory: The case of phonology.

Finley, S. (2004). *Morphological influences on vowel harmony*.Unpublished manuscript, Johns Hopkins Unviversity.

Finley, S. (2006). Vowel harmony in Korean and morpheme correspondence. *Harvard Studies in Korean Linguistics, 11*, 131-144.

Finley, S. (in preparation). *Morphemic vowel harmony as featural correspondence*.Unpublished manuscript, Johns Hopkins University.

Finley, S. (submitted). *Exceptions in vowel harmony are local*.Unpublished manuscript, Johns Hopkins University.

Finley, S., & Badecker, W. (2008). Towards a substantively biased theory of learning. *BLS, 33*.

Finley, S., & Badecker, W. (in press-a). Analytic biases for vowel harmony languages. *WCCFL, 27*.

Finley, S., & Badecker, W. (in press-b). Right-to-left biases for vowel harmony: Evidence from artificial grammar. *NELS, 38*.

Flemming, E. (1995). *Auditory Representations in Phonology*. UCLA.

Fromkin, V. (1973). *Speech errors as linguistic evidence*. The Hague: Mouton.

Gerken, L. (2002). Early sensitivity to linguistic form. *Annual Review of Language Acquisition, 2*, 1-36.

Goldrick, M. (1999). *Optimal opacity: Covert structure in phonology*.Unpublished manuscript, Johns Hopkins University.

Goldrick, M. (2001). Turbid output representations and the unity of opacity. *NELS, 30*, 231-245.

Goldrick, M. (2002). *Patterns of sound, patterns in mind: Phonological regularities in speech production*. Unpublished doctoral dissertation, Johns Hopkins University, Baltimore.

Goldrick, M. (2004). Phonological features and phonotactic constraints in speech production. *Journal of Memory and Language, 56*, 586-603.

Goldsmith, J. (1975). *Tone melodies and the autosegment*. Paper presented at the Proceedings of the 6th Conference on African Linguistics.

Goldsmith, J. (1993). Harmonic phonology. In J. Goldsmith (Ed.), *the last phonological rule* (pp. 20-60). Chicago: The University of Chicago Press.

Gomez, R. L., & Gerken, L. (1999). Artificial grammar learning by 1-year-olds leads to specific and abstract knowledge. *Cognition, 79*, 109-135.

Guest, D. J., Dell, G. S., & Cole, J. (2000). Violable constraints in language production: Testing the transitivity assumption of Optimality Theory. *Journal of Memory and Language, 42*, 272-299.

Gussmann, E. (1986). The unnatural phonology of Icelandic and Polish velar palatalisations. *Studia Anglica Posmanemsta, 18*, 37-57.

Hahn, U., Bailey, T. M., & Elvin, L. B. C. (2005). Effects of category diversity on learning, memory, and generalization. *Memory and Cognition, 33*, 289-302.

Hall, B. L., & Hall, R. M. R. (1980). Nez Perce vowel harmony: An Africanist explanation and some theoretical consequences. In R. M. Vago & (ed.) (Eds.), *Issues in vowel harmony* (pp. 201-236). Amsterdam: John Benjamins.

Hall, B. L., Hall, R. M. R., Pam, M. D., Meyers, A., Antell, S. A., & Cherono, G. K. (1973). African vowel harmony systems from the vantage point of Kalenjin. *Afrika und Uberse, 57*(241-267).

Hansson, G. O. (2001). *Theoretical and typological issues in consonant harmony*. University of California, Berkeley, Berkeley.

Harrison, K. D. (1999). *Vowel harmony and disharmony in Tuvan and Tofa*. Paper presented at the 2nd Asian G.L.O.W.

Hayes, B. (1995). *Metrical stress theory: principles and case studies*. Chicago: University of Chicago Press.

Hayes, B. (1997). *Phonetically driven phonology: The role of Optimality Theory and indudtive grounding*. Paper presented at the Milwaukee Conference on Formalism and Functionalism in Linguistics.

Hayes, B. (1999). Phonetically driven phonology: The role of Optimality Theory and inductive grounding. In M. Darnell, E. Moravsik, M. Noonan, F. Newmeyer & K. Wheatley (Eds.), *Functionalism and formalism in linguistics: Volume 1. General papers* (pp. 243-286). Amsterdam: John Benjamins.

Hayes, B. (2001). Phonological acquisition in Optimality Theory: The early stages.

Hayes, B., & Londe, Z. C. (2006). Stochastic phonological knowledge: The case of Hungarian vowel harmony. *Phonology, 23*, 59-104.

Hayes, B., & Steriade, D. (2004). The phonetic bases of phonological markedness. In B. Hayes, R. Kirchner & D. Steriade (Eds.), *Phonetically based phonology* (pp. 1-33). Cambridge: Cambridge University Press.

Hayes, B., & Wilson, C. (to appear). A Maximum Entropy Model of Phonotactics and Phonotactic Learning. *Linguistic Inquiry*.

Hellberg, S. (1978). Unnatural phonology. *Journal of Linguistics, 14*, 157-177.

Hualde, J.-I. (1989). Autosegmental and metrical spreading in the vowel harmony systems of northwestern Spain. *Linguistics, 27*(5), 773-805.

Hualde, J. I. (1992). Metaphony and count/mass morphology in Asturian and Cantabrian dialects. In C. Laeuffer & T. A. Morgan (Eds.), *Theoretical Analyses in Romance Linguistics* (pp. 99-114). Amsterdam: John Benjamins Publishing.

Hyman, L. H. (1999). The historical interpretation of vowel harmony in Bantu. In *Bantu historical linguistics: Theoretical and empirical perspectives* (pp. 235-395).

Hyman, L. H. (2002a). "Abstract" vowel harmony in Kalong: A system driven account. *Theories Linguistiques et Langues Sub-Sahariennes, 8*, 1-22.

Hyman, L. H. (2002b). Is there a right-to-left bias in vowel harmony. *9th International Phonology Meeting*.

Ito, J., & Mester, A. (1995). The core-periphery structure of the lexicon and constraints on reranking. In J. N. Beckman, L. W. Dickey & S. Urbanczyk (Eds.), *Papers in Optimality Theory* (Vol. 18, pp. 181-209). Amherst: GLSA.

Jacobson, L. C. (1980). Voice-quality in Western Nilotic languages. In *Issues in Vowel Harmony* (pp. 183-199).

Jaeger, J. J. (1986). On the acquisition of abstract representations for English Vowels. *Phonology Yearbook, 3*, 71-97.

Jakobson, R. (1968). *Child language, aphasia and phonological universals*. The Hague: Mouton.

Johnson, K. (1997). Speech perception without speaker normalization. In K. Johnson & J. W. Mullenix (Eds.), *Talker variability in speech processing* (pp. 145-165). San Diego: Academic Press.

Johnson, K. (2005). *Decisions and mechanisms in exempar-based phonology*.Unpublished manuscript.

Jusczyk, P., & Aslin, R. N. (1995). Infants' detection of the sound patterns of words in fluent speech. *Cognitive Psychology, 29*(1-23).

Jusczyk, P., Smolensky, P., & Alloco, T. (2002). How English-learing infants respond to markedness and faithfulness constraints. *Language Acquisition, 10*, 31-73.

Kaplan, A. (2007). *The nature of iterativity: Evidence from Lango*.Unpublished manuscript, UCSC.

Kaplan, A. (2008). Licensing and noniterative harmony in Lango. *NELS, 37*.

Kaun, A. (1995). *The typology of rounding harmony: An optimality theoretic approach*. UCLA, Los Angeles.

Kaun, A. (2004). The typology of rounding harmony. In B. Hayes & D. Steriade (Eds.), *Phonetics in Phonology* (pp. 87-116). Cambridge: Cambridge University Press.

Kawahara, S. (2007). Copying and spreading in phonological theory: Evidence from echo epenthesis. In L. Bateman, M. O'Keefe, E. Reilly & A. Werle (Eds.), *UMOP 32: Papers in Optimality Theory III* (pp. 111-144). Amherst, MA: GLSA.

Kemler Nelson, D., Hirsh-Pasek, K., Jusczyk, P., & Cassidy, K. W. (1989). How prosodic cues in motherese might assist language learning. *Journal of Child Language, 16*, 55-68.

Kenstowicz, M. (1979). Chukchee vowel harmony and epenthesis. *Chicago Linguistics Society*(parasession), 402-412.

Kersten, A. W., & Earles, J. L. (2001). Less really is more for adults learning a miniature artificial language. *Journal of Memory and Language, 44*, 250-273.

Kingston, J. (2003). Learning foreign vowels. *Language and Speech, 26*(2-3), 295-249.

Kiparsky, P. (1973). Phonological representations. In O. Fujimura & (ed.) (Eds.), *Three dimensions of phonological theory* (pp. 5-56). Tokyo: TEC Company.

Kiparsky, P. (1981). *Vowel harmony*.Unpublished manuscript, MIT.

Kiparsky, P. (2000). Opacity and cyclicity. *The Linguistic Review, 17*, 351-365.

Kiparsky, P., & Pajusalu, K. (2003). Towards a typology of disharmony. *The Linguistic Review, 20*, 217-241.

Kirchner, R. (1993). *Turkish vowel harmony and disharmony: An Optimality Theoretic account*. Paper presented at the Rutgers Optimality Workshop I (ROW-I).

Kirchner, R. (2004). Exemplar-based phonology: It's about time. *WCCFL, 23*, 464-474.

Kitto, C., & DeLacy, P. (1999). Correspondence and epenthetic quality. In C. Kitto & C. Smallwood (Eds.), *Proceedings of AFLA VI*. Holland: Academic Graphics.

Kramer, M. (2002). *Vowel transparency as balance*. Paper presented at the SCL, Tromso, Norway.

Krämer, M. (2003). *Vowel harmony and correspondence theory* (Vol. 66). Berlin: Mouton de Gruyter.

Legendre, G. (2001). An introduction to Optimality Theory in syntax. In G. Legendre, J. Grimshaw & S. Vikner (Eds.), *Optimality-Theoretic syntax* (pp. 1-21). Cambridge: MIT Press.

Legendre, G., Hagstrom, P., Vainikka, A., & Todorova, M. (2002). Partial constraint ordering in child French syntax. *Language Acquisition, 10*(3), 189-227.

Linebaugh, G., & Cole, J. (2005). *Does vowel harmony facilitate speech production?* Paper presented at the McWOP, University of Michigan.

Lodge, K. (1995). Kalenjin phonology and morphology: A further exemplificiation of underspecification and non-destructive phonology. *Lingua, 96*, 29-43.

Lombardi, L. (1999). Positional faithfulness and voicing assimilation in optimality theory. *NLLT, 17*, 267-302.

Lubowicz, A. (2005). Locality of conjunction. *WCCFL, 24*.

Mahanta, S. (2007). *Directionality and locality in vowel harmony: With special reference to vowel harmony in Assamese*. Utrecht Institute of Linguistics.

Marslen-Wilson, W. (1975). Sentence perception as an interactive parallel process. *Science, 189*, 226-228.

Martin, B. (1985). Vowel harmony in Kipsigis. *Studies in African Linguistics, Supplement 9*, 215-219.

Masson, M. E., & Loftus, G. R. (2003). Using confidence intervals for graphically based data interpretation. *Canadian Journal of Experimental Psychology, 57*, 203-220.

Maye, J., Werker, J., & Gerken, L. (2002). Infant sensitivity to distributional information can affect phonetic discrimination. *Cognition, 82*, B101-B111.

McCarthy, J. J. (1984). Theoretical consequences of Montanes vowel harmony. *LI, 15*(2), 291-318.

McCarthy, J. J. (2004). *Headed Spans and Autosegmental Spreading*.Unpublished manuscript, UMass, Amherst.

McCarthy, J. J. (2007). *Hidden generalizations: Phonological opacity in Optimality Theory*. London: Equinox.

McCarthy, J. J., & Prince, A. (1995). Faithfulness and reduplicative identity. In J. M. Beckman, L. W. Dickey, S. Urbanczyk & (eds.) (Eds.), *Papers in optimality theory* (pp. 249-384). Amherst: GLSA.

Michaels, D. (1988). Natural and unnatural phonology. In W. U. Dressler, H. C. Luschutszky, O. E. Pfeiffer & J. R. Rennison (Eds.), *Phonologica 1988*. Cambridge: Cambridge University Press.

Miner, K. L. (1979). Dorsey's law in Winnebego-Whiere and Winnebego accent. *International Journal of American Linguistics, 45*, 25-33.

Moren, B. (2003). The parallel structures model of feature geometry. *Working Papers of the Cornell Phonetics Laboratory, 15*, 194-270.

Moreton, E. (2008). Analytic Bias as a Factor in Phonological Typology. *WCCFL, 27*.

Moreton, E. (in prep). Modularity Bias in Phonological Pattern Learning. *WCCFL, 27*.

Moreton, E. (in press). Phonotactic learning and phonological typology. *Phonology*.

Moreton, E., & Smolensky, P. (2002). Typological consequences of local constraint conjunction. *WCCFL, 21*.

Nevins, A. I. (2004). *Conditions on (dis)harmony*. Massachusetts Institute of Technology.

Newport, E., & Aslin, R. N. (2004). Learning at a distance I. Statistical learning of non-adjacent dependencies. *Cognitive Psychology, 48*, 127-162.

NiChisosain, & Padgett, J. (2001). Markedness, segment realization and locality in spreading. In L. Lombardi (Ed.), *Segmental phonology in Optimality Theory* (pp. 118-156). Cambridge: Cambridge University Press.

Noske, M. (1990). Vowel harmony in Turkana. *Studies in the Lingusitic Sciences, 20*, 123-134.

Noske, M. (2000). [ATR] harmony in Turkana: A case of faith suffix >> faith root. *NLLT, 18*, 771-812.

Nosofsky, R. (1986). Attention, similarity and the identification-categorization relationship. *Journal of Experimental Psychology: General, 115*, 39-57.

Nosofsky, R. (1988). Exemplar-based accounts of relations between classification, recognition and typicality. *Journal of Experimental Psychology: Learning, Memory and Cognition, 14*(4), 700-708.

O'Keefe, M. (2007). Transparency in span theory. In L. Bateman, A. Werle, M. O'Keefe & E. Reilly (Eds.), *University of Massachusetts Occasional Papers in Linguistics 33: Papers in Optimality 3* (pp. 239-258). Amherst, MA: GLSA.

Ohala, J. J. (1994). The frequency code underlies the sound-symbolic use of pitch. In L. Hinton & J. J. Ohala (Eds.), *Sound symbolism* (pp. 115-129). Cambridge: Cambridge University Press.

Okello, B. J. (1975). *Some phonological and morphological processes in Lango*. Indiana University.

Onishi, K. H., Chambers, K. E., & Fisher, C. (2002). Learning phonotactic constraints from brief auditory experience. *Cognition, 83*, B13-B23.

Onnis, L., Monaghan, P., Richmond, K., & Chater, N. (2005). Phonology impacts segmentation in online speech perception. *Journal of Memory and Language, 53*, 225-237.

Orie, O. O. (2001). An alignment-based account of vowel harmony in Ife Yoruba. *Journal of African Language and Linguistics, 22*, 117-143.

Orie, O. O. (2003). Two harmony theories and vowel patterns in Ebira and Yoruba. *The Linguistic Review, 20*, 1-35.

Paster, M. (2004). Vowel height harmony and blocking in Buchan Scots. *Phonology, 21*, 359-407.

Pater, J., & Tessier, A.-M. (2003). *Phonotactic knowledge and the acquisition of alternations*. Paper presented at the ICPhS, Barcelona.

Pearce, M. (2003). *Vowel harmony in Kera (Chadic)*.Unpublished manuscript, University College, London.

Pena, M., Bonatti, L. L., Nespor, M., & Mehler, J. (2002). Signal-drivel computations in speech processing. *Science Express, 10*, 1-6.

Penny, R. J. (1969). Vowel harmony in the speech of Montanes de Pas. *ORBIS- Bulletin International de Documentation Linguistique*, 148-166.

Penny, R. J. (1970). Mass-nouns and metaphony in the dialects of north-western Spain. *Archivum Linguisticum, 1*, 21-30.

Penny, R. J. (1972). Verb-class as a determiner of stem-vowel in the historical morphology of Spanish verbs. *Revue de Linguistique Romane, 36*, 343-359.

Peperkamp, S., & Dupoux, E. (2002). A typological study of stress 'deafness'. In C. Gussenhoven & N. Warner (Eds.), *Laboratory Phonology 7* (pp. 203-240). Berlin: Mouton de Gruyter.

Peperkamp, S., & Dupoux, E. (to appear). Learning the mapping from surface to underlying representations in artificial language. In J. Cole & J. I. Hualde (Eds.), *Laboratory Phonology 9*.

Peperkamp, S., Le Calvez, R., Nadal, J.-P., & Dupoux, E. (2006). The acquisition of allophonic rules: Statistical learning with linguistic constraints. *Cognition*.

Peperkamp, S., Skoruppa, K., & Dupoux, E. (2006). *The role of phonetic naturalness in phonological rule acquisition*. Paper presented at the Boston University Conference on Language Development.

Piccard, M. (2001). Vowel harmony, centralization and peripherality: the case of Pasiego. *Linguistics, 39*(1), 117-132.

Pierrehumbert, J. (2000). Exemplar dynamics: Word frequency, lenition and constrast. In J. L. Bybee & P. Hopper (Eds.), *Frequency effects and emergent grammar*. Amsterdam: John Benjamins.

Pierrehumbert, J. (2003). Phonetic diversity, statistical learning, and acquisition of phonology. *Language and Speech, 46*, 115-154.

Polgardi, K. (1999). Vowel harmony and disharmony in Turkish. *The Linguistic Review, 16*(2), 187-204.

Port, R. F., & Leary, A. P. (2005). Agaisnt formal phonology. *Language, 81*, 927-964.

Poser, W. J. (1982). Phonological representation and action-at-a-glance distance. *GLOW Newsletter, 8*, 121-158.

Postal, P. M. (1968). Mohawk vowel doubling. *International Journal of American Linguistics, 35*, 291-298.

Prince, A. (2002). Arguing optimality. In A. Coetzee, A. Carpenter & P. De Lacy (Eds.), *Papers in Optimality Theory II*. Amherst, MA: GLSA.

Prince, A., & Smolensky, P. (1993/2004). *Optimality theory: Constraint interaction in generative grammar*. Cambridge: Blackwell.

Prince, A., & Smolensky, P. (2006). Optimality in phonology I: Syllable structure. In P. Smolensky & G. Legendre (Eds.), *The harmonic mind: From neural computation to Optimality-Theoretic grammar* (Vol. 2. Linguistic and philosophical implications, pp. 3-26). Cambridge, MA: The MIT Press.

Pulleyblank, D. (2002). Harmony drivers: No disagreement allowed. *BLS*(28), 249-267.

Pycha, A., Nowak, P., Shin, E., & Shosted, R. (2003). Phonological rule-learning and its implications for a theory of vowel harmony. *WCCFL, 22*, 101-113.

Reber, A. S. (1967). Implicit learning of artificial grammars. *Journal of Verbal Learning and Verbal Behavior, 6*, 855-863.

Reber, A. S. (1976). Implicit learning of synthetic languages: the role of instructional set. *Journal of Experimental Psychology: Human Learning and Memory, 2*, 88-94.

Redington, M., & Chater, N. (1996). Transfer in artificial grammar learning: A reevaluation. *Journal of Experimental Psychology: General, 125*(2), 123-138.

Revithiadou, A. (to appear). Colored Turbid accents and containment: A case study from lexical stress. In S. Blaho, P. Bye & M. Kramer (Eds.), *Freedom of Analysis*. Berlin: Mouton De Gruyter.

Ribeiro, E. R. (2002). Directionality in vowel harmony: The case of Karaja (Macro Je). *BLS, 28*.

Riggle, J. (1999). *Relational markedness in Bantu vowel height harmony*.Unpublished manuscript, Los Angeles.

Riggle, J. (2004). *Generation, recognition and learning in finite-state Optimality Theory*. UCLA.

Rose, Y., & Demuth, K. (2006). Vowel epenthesis in loanword adaptation: Representational and phonetic considerations. *Lingua, 116*, 1112-1139.

Rottland, F. (1983). Southern Nilotic (with an outline of Datooga). In M. L. Bender & (ed.) (Eds.), *Nilo-Saharan Language Studies* (Vol. 13, pp. 208-238). East Lansing: African Studies Center, University of Michigan.

Saffran, J. R. (2001). Words in a sea of sounds: the output of infant statitical learning. *Cognition, 81*, 149-169.

Saffran, J. R. (2002). Contraints on statitical learning. *Journal of Memory and Language, 47*, 172-196.

Saffran, J. R. (2003a). From syllables to syntax: Multilevel statistical learning by 12-month-old infants. *Infancy, 4*, 273-284.

Saffran, J. R. (2003b). Statistical language learning: Mechanisms and constraints. *Current Directions in Psychological Science, 12*(4), 110-114.

Saffran, J. R., Aslin, R. N., & Newport, E. (1996). Statistical learning by 8-month-olds. *Science, 274*, 1926-1928.

Saffran, J. R., Newport, E., Aslin, R. N., Tunick, R. A., & Barrueco, S. (1997). Incidental language learning: Listening (and learning) out of the corner of your ear. *Psychological Science, 8*, 101-105.

Saffran, J. R., Reeck, K., Niebuhr, A., & Wilson, D. (2005). Changing the tune: the sturcture of the input affects infants' use of absolute and relative pitch. *Developmental Science, 8*(1), 1-7.

Sagey, E. (1987). *Non-constituent spreading in Barra Gaelic*.Unpublished manuscript, UC Irvine.

Schane, S., Tranel, B., & Lane, H. (1974). On the psychological reality of a natural rule of syllable structure. *Cognition, 3*, 351-358.

Seidl, A., & Buckley, E. (2005). On the learning of arbitrary phonological rules. *Language Learning and Development, 1*, 289-316.

Seidl, A., & Buckley, E. (2006). *Complexity, not naturalness, in infant phonological pattern learning*.Unpublished manuscript, Purdue University.

Shademan, S. (2002). *Epenthetic vowel harmony in Farsi*. UCLA, Los Angeles.

Shukla, M., Nespor, M., & Mehler, J. (2007). An interaction between prosody and statistics in the segmentation of fluent speech. *Cognitive Psychology, 54*, 1-32.

Smolensky, P. (2006). Optimality in phonology II: Harmonic completeness, local constraint conjunction, and feature-domain markedness. In P. Smolensky, G. Legendre & (eds.) (Eds.), *The Harmonic Mind: From Neural Computation to Optimality-Theoretic Grammar, Volume II* (pp. 27-160): MIT Press.

Smolensky, P., Legendre, G., & Tesar, B. (2006). Optimality Theory: The structure, use and acquisition of grammatical knowledge. In P. Smolensky & G. Legendre (Eds.), *The harmonic mind: From neural computation to Optimality-Theoretic grammar: Volume 1: Cognitive Architechture* (pp. 453-535). Cambridge, MA: MIT Press.

Soderstrom, M., Mathis, D. W., & Smolensky, P. (2006). Abstract genomic encoding of universal grammar in Optimality Theory. In P. Smolensky & G. Legendre (Eds.), *The harmonic mind: From neural computation to Optimality-Theoretic grammar* (Vol. 2. Linguistic and philosophical implications, pp. 403-471). Cambridge, MA: The MIT Press.

Steriade, D. (2000). Directional asymmetries in place assimilation: A perceptual account. In E. Hume & K. Johnson (Eds.), *Perception in Phonology*.

Steriade, D. (2001). *The Phonology of Perceptibility Effects: the P-map and its consequences for constraint organization*.Unpublished manuscript, MIT.

Stevenson, S., & Smolensky, P. (2006). Optimality in sentence processing. In P. Smolensky & G. Legendre (Eds.), *The harmonic mind: From neural computation to Optimality-Theoretic grammar* (Vol. 2. Linguistic and philosophical implications, pp. 307-336). Cambridge, MA: The MIT Press.

Suomi, K., McQueen, J., & Cutler, A. (1997). Vowel harmony and speech segmenation in Finnish. *Journal of Memory and Language, 36*, 422-444.

Tesar, B., & Smolensky, P. (1998). Learnability in Optimality Theory. *Linguistic Inquiry, 29*, 229-268.

Tessier, A.-M. (2007). *Biases and stages in phonological acquisition*. UMass, Amherst, Amherst.

Tessier, A.-M. (submitted). Testing the effects of OO-Faithfulness across stages of cluster acquisition. *Language Acquisition*.

Toro, J. M., Sinnett, S., & Soto-Faraco, S. (2005). Speech segmentation by statistical learning depends on attention. *Cognition, 97*, B25-B34.

Uffmann, C. (2006). Epenthetic vowel quality in loanwords: Empirical and formal issues. *Lingua, 116*, 1079-1111.

Underhill, R. (1976). *Turkish grammar*. Cambridge: MIT Press.

Vago, R. M. (1973). Abstract vowel harmony systems in Uralic and Altaic languages. *Lg, 49*(3), 579-603.

Vago, R. M. (1988). Underspecification in the height system of Pasiego. *Phonology, 5*, 343-362.

van der Hulst, H., & van de Weijer, J. (1995). Vowel harmony. In J. Goldsmith (Ed.), *The handbook of phonological theory* (pp. 495-531). Oxford: Blackwell.

van Oostendorp, M. (2006a). *Derived environment effects and consistency of exponence*.Unpublished manuscript, ROA.

van Oostendorp, M. (2006b). *Incomplete devoicing in formal phonology*.Unpublished manuscript, ROA 851-0706.

van Oostendorp, M. (2007). *Phonological feature domains and the content of epenthetic vowels*. Paper presented at the GLOW Conference on Features.

van Oostendorp, M., & Revithiadou, A. (2005). *Quasi-opacity and headed spans in Silly and Megisti Greek*. Paper presented at the Manchester Phonology Meeting.

Vaux, B. (1995). Vowel harmony in the Armenian dialect of Karchevan. *NSL, 9*(1-9).

Vaux, B. (1998). *The phonology of Armenian*. Oxford: Clovendon Press.

Vroomen, J., Tuomainen, J., & deGelder, B. (1998). The role of word stress and vowel harmony in speech segmentation. *Journal of Memory and Language, 38*, 133-149.

White, K., Peperkamp, S., Kirk, C., & Morgan, J. L. (2008). Rapid acquisition of phonological alternations by infants. *Cognition, 107*, 238-265.

Wilson, C. (2000). *Targeted constraints: An approach to contextual neutralization in Optimality Theory*. Johns Hopkins University, Baltimore, MD.

Wilson, C. (2001). Consonant cluster neutralisation and targeted constraints. *Phonology, 18*, 147-197.

Wilson, C. (2003a). *Analyzing unbounded spreading with constraints: Marks, targets, and derivations*.Unpublished manuscript, UCLA.

Wilson, C. (2003b). Experimental investigations of phonological naturalness. *WCCFL, 22*, 101-114.

Wilson, C. (2006). Learning phonology with substantive bias: An experimental and computational study of velar palatalization. *Cognitive Science, 30*, 945-982.

Wiltshire, C. (1992). *Syllabification and rule application in harmonic phonology*. University of Chicago.

Woock, E. B., & Nooonan, M. (1979). Vowel harmony in Lango. *CLS, 15*, 20-29.

Yarmolinskaya, J. (2005). Russian palatalization and opacity in Optimality Theory. In S. Franks, F. Y. Gladney & M. Tasseva-Kurtchieva (Eds.), *Formal approaches to Slavic linguistics* (Vol. 13, pp. 376-386). Ann Arbor, MI: Michigan Slavic Publications.

Curriculum Vitae

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