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Sources of Non-conformity in Phonology: Variation and Exceptionality in Modern Hebrew Spirantization (Dissertation)

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SOURCES OF NON-CONFORMITY IN PHONOLOGY:

VARIATION AND EXCEPTIONALITY IN

MODERN HEBREW SPIRANTIZATION

by

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Dedication

To my grandparents
for instilling in me a love for language

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Abstract

This dissertation investigates the integration of two sources of non-conformity – exceptionality and variation – in a single phonological system. Exceptionality manifests itself as systematic non-conformity, and variation as partial or variable non-conformity. When both occur within the same phenomenon, this is particularly challenging for the linguistic system. Modern Hebrew spirantization provides an apt case study for the investigation of the interaction of these two sources of non-conformity where exceptional (non-alternating) segments are frequent, and variation in alternating segments has been reported (Adam 2002). This dissertation makes contributions in the forms of both data and analysis. Its goals are to provide a description of exceptionality and variation in Modern Hebrew spirantization and an analysis which incorporates alternation, exceptionality and variation.

To collect data for the description of Modern Hebrew spirantization in verbal paradigms, an experimental rating task was conducted. Its goal was to examine speakers' acceptance of variation in both alternating and exceptional segments in Modern Hebrew spirantization, where stops and fricatives alternate, with the latter occurring in post-vocalic contexts and the former occurring elsewhere. The results establish that variation is at least somewhat acceptable in both alternating and exceptional segments, and is significantly more acceptable in alternating segments than in exceptional ones. Moreover, speakers showed a preference for the expected forms of both types of segments (i.e. the non-alternating form in exceptions, and post-vocalic fricatives or word-initial and post-

consonantal stops in alternating segments). Importantly, the results also show that variation in both types of segments is gradient.

To account for alternation, exceptionality, and variation in relation to a single phonological process, I propose a model combining the set-indexation approach for exceptionality (Pater 2000) with stochastic OT and the Gradual Learning Algorithm for gradience in variation (Boersma 1998, Hayes & MacEachern 1998, Zuraw 2000, Boersma & Hayes 2001, Hayes & Londe 2006). I call this the 'combined model'. I show that neither approach is able to account for both sources of non-conformity on its own; set-indexation allows only for categorical distinctions between alternation and exceptionality, whereas ranking distributions in stochastic OT limit the possible range of constraint interactions to account only for variation.

Looking forward, implementing the acquisition of these patterns in current models of the learning algorithms results in a paradox. In particular, set-indexation and stochastic constraint rankings both presuppose that the mechanism they do not account for is established by a different mechanism – set-indexation is only implemented once variation and speech errors have been ruled out as the cause for non-alternation, whereas in order to provide the stochastic constraint rankings accounting for acceptability of variation in all tokens, set-indexation must have already been implemented. This study therefore opens new avenues for research involving learning algorithms and their handling of non-conformity.

1 Introduction

In this dissertation I investigate how two sources of non-conformity – exceptionality and variation – are integrated into a single phonological system along with patterns of conformity. While exceptionality is manifested as systematic non-conformity, and variation as partial or variable non-conformity, the interaction of both sources can be particularly challenging for the linguistic system.

One such case is presented in Modern Hebrew spirantization where, due to historical sound mergers and more recent borrowings, exceptional (non-alternating) segments are frequent in the grammar, and variation has been reported in alternating segments (Adam 2002).

In this dissertation, I approach the phenomena under study in various ways. An experiment examining the acceptability of variation in Modern Hebrew spirantization provides a depiction of the current state of alternation and non-conformity in the grammar. The formal theoretical analysis proposed in this dissertation for handling two sources of non-conformity in a single grammar combines two distinct mechanisms needed to handle exceptionality and variation. Questions about the implications that combining these different components of the grammar has for phonological acquisition are also raised.

1.1 Exceptionality and Variation as sources of non-conformity

It is often the case that particular instances of elements in the grammar (i.e. segments, morphemes, words) do not conform in ways that are predicted or explained by the general patterns of the language.

In rule-based phonology, one way variation was accounted for was rule optionality, with the option to account for rule application probability through special calculation marked by notation for variable rules (Labov 1969). However, there was substantial disagreement as to the exactly how probability should be used to account for different patterns of variation (Postal 1968). In more recent years, especially within the Optimality Theoretic (Prince & Smolensky 1993) framework, the ability to more accurately account for statistical tendencies in variation has led to new approaches based on partially ordered constraints (Anttila 1997, Guy 1997, Anttila & Cho 1998, Ringen & Heinämäki 1999). These models allow for partial constraint rankings which calculate statistical probabilities based on the number of times a particular pattern surfaces given the possible rankings. Other probabilistic approaches to variation account for the acquisition of phonological variation through weighted constraint rankings, which, along with a fixed distribution for the constraints involved, determine the probability of variation in the output of each learning trial (Boersma 1997, 1998, Zuraw 2000, Boersma & Hayes 2001).

Accounts for exceptional patterns appear as early as SPE where diacritics depicted exceptionality and minor rules, which applied less frequently than other rules in the grammar, accounted for lexical exceptions (Chomsky & Halle 1968). In more recent accounts for exceptionality, approaches have included prespecification and underspecification (Itô et al. 1995, Inkelas et al. 1997, Albright 2002), lexical stratification (Itô & Mester 1995, Fukuzawa 1999, Itô & Mester 1999), and lexically specific constraints (Pater 2000, 2005, 2006). Additionally, probabilistic models have sought to model exceptionality as a product of the frequency of regular and exceptional patterns surfacing in the grammar (Zuraw 2000, Becker 2009).

In this dissertation I will focus on sources of non-conformity to an allophonic alternation that produces a complementary distribution. Allophonic distributions are characterized in rule form as X → Y/ A_B, where Y, a variant or allophone of X, occurs in the environment A_B. Non-conformity to the resulting complementary distribution includes instances of X in the context A_B and instances of Y resulting from the above rule in contexts other than A_B. Instances of non-conformity are traditionally classified as either *exceptionality* or *variation*, defined in (1).

(1) Definition of Exceptionality and Variation

Exceptionality is patterned (or systematic) non-conformity, and *variation* is partial (or variable) non-conformity with respect to a given linguistic phenomenon.

In this work, I will explore the types of non-conformity in (1) in some depth and examine their implications for the nature of representations and constraints in phonological theory. As discussed in Chapter 3, the distinction between exceptionality and variation is not always entirely categorical – as some variation is deemed acceptable in exceptions.

In phonological representations, exceptions may include segments (Inkelas et al. 1997), syllables (Itô & Mester 1995), morphemes (Pater 2006), or other constituents that do not conform to a pattern. They can also be a source of exceptionality by preventing other parts of the word from conforming. Exceptions may have diachronic or etymological bases. For example, borrowings in Japanese display different degrees of conformity to native phonological patterns based, in part, on their language of origin (Itô & Mester 1995, 1999). Borrowings from Chinese generally contain fewer sources of non-conformity to native Yamato patterns than words borrowed into the language more recently from other foreign languages, such as English.

In Chapter 2, I describe Modern Hebrew spirantization, a phenomenon for which there are phonetically identical segments that differ in their degree of conformity depending on whether they are descended from a segment that conformed to spirantization in Tiberian Hebrew, an older form of the language. Additionally, there are more recent borrowings from other Semitic languages, as well as Germanic and Slavic languages, whose segments also fail to follow the native phonological patterning of Moden Hebrew. In addition to these exceptions, there is variation in segments that normally conform to spirantization (Adam 2002).

Variation occurs when there are multiple acceptable forms, or variants, for a given element of the grammar. Forms may vary across speakers, dialects and registers. Phonologically, this can be instantiated in the form of multiple pronunciations of a segment, multiple plausible placements of stress, or multiple acceptable syllable structures and sound combinations, among other possibilities. Although multiple variants are deemed acceptable, it is not necessarily the case that they are equally acceptable, or in free distribution. As discussed in Anttila (1995) and reported in the experiment described in Chapter 3, native speakers usually prefer one variant over another.

An example of phonological variation in English is the deletion of word-final [t] or [d] in some varieties (Coetzee 2004). This deletion is conditioned by the following segment, with deletion occurring more often when the following word begins with a consonant. Deletion is less common in phrase-final position or when the following word begins with a vowel. Looking across several varieties and across these three positions, Coetzee find that there are varying degrees of deletion, none of which is in truly free variation with any other. For example, when followed by a vowel sound, the variant maintaining the [t] or [d] is preferred to the variant in which it is omitted. This is the case in Tejano English where speakers prefer deleting the [t] or [d] in pre-consonantal context 62% of the time, whereas maintaining the [t] or [d] in pre-vocalic context is preferred to deletion 75% of the time.

As reported in Chapter 3, in Modern Hebrew spirantization variation is more acceptable in segments that normally alternate than in exceptional segments. The following section outlines alternation, exceptionality and variation in Modern Hebrew spirantization.

1.2 Modern Hebrew Spirantization

Modern Hebrew spirantization is relevant to the study of the integration of exceptionality and variation as both sources of non-conformity are represented within this phenomenon, alongside regular alternation.

In Modern Hebrew, spirantization is characterized as the alternation between the stops [p], [b], and [k] and the fricatives [f], [v], and [χ], respectively. These consonant pairs occur in complementary distribution – fricatives surface in post-vocalic position whereas stops surface in word-initial and post-consonantal positions. In (2), we see this distribution in three roots; /pgʃ/, /bgd/, and /ktb/. In each of the roots, the root initial consonant occurs in post-vocalic position in the infinitive, resulting in a fricative. An additional conjugation of the roots where the consonant is word-initial and instantiated as a stop is included to show the alternation within verbal paradigms. In alternating segments, I assume stops to be the underlying form for descriptive purposes.[1]

(2) Examples of spirantization in Modern Hebrew

	Root	Infinitive	3rd Person Sg. Past.m.	
/p/ → [f]	/**p**gʃ/	[li**f**goʃ]	[**p**agaʃ]	'to meet'
/b/ → [v]	/**b**gd/	[li**v**god]	[**b**agad]	'to betray'
/k/ → [χ]	/**k**tb/	[li**χ**tov]	[**k**atav]	'to write'

In addition to the complementary distribution described in (2), there are non-alternating segments which are the consequences of historical sound mergers and more recent borrowings. Exceptionality is a result of non-alternation within paradigms – lack

[1] In Section 2.7.1, I provide an analysis of these alternating paradigms that allows the underlying representation to be either a stop or a fricative.

of alternation leads to exceptional stops surfacing in post-vocalic contexts and fricatives surfacing in word-initial and post-consonantal contexts, as seen in the underlined words in (3). In non-alternating segments, I assume the underlying segment to correspond to the surface forms.

(3) Exceptions to spirantization in Modern Hebrew (in underlined words)

	Root	**3rd Person Sg. Past**	**Infinitive**	
/k/	/**k**rʔ/	[**k**ara]	[li**k**ro]	‘to read’
/v/	/**v**tr/	[**v**iter]	[le**v**ater]	‘to give up’

I argue that exceptions in Modern Hebrew spirantization must be encoded at the segmental level. This is due to the existence of words and roots containing both an alternating segment and a non-alternating exceptional segment, which I refer to as *hybrids*. Since not all segments in a given word must behave the same way with regard to spirantization, they must be individually evaluated, allowing alternation and exceptionality within the same word. Examples of hybrid roots and words are given in (4) with an alternating /b/ (which surfaces as [v] in post-vocalic context) and a non-alternating /k/ (which is exceptional in post-vocalic context, in bold).

(4) Hybrid roots and words

Root	**3rd Person Sg. Past**	**Infinitive**	
/bkr/	[bi**k**er]	[leva**k**er]	‘to visit
/kbr/	[kavar]	[li**k**bor]	‘to bury’

In addition to exceptional segments, variation has also been documented in Modern Hebrew spirantization (Adam 2002). Variants of alternating segments are occasionally produced, resulting in non-conformity to the general alternation pattern. This variation can be either between speakers or within speakers (across different registers). Some examples of variation are shown in Table 1.

Table 1. Variation in Modern Hebrew spirantization

Expected	Acceptable Variant	Gloss
pagaʃ	**f**agaʃ	'met'
jik**b**or	jik**v**or	'will bury'
je**χ**ase	je**k**ase	'will cover'

In summary, Modern Hebrew spirantization is a phenomenon which is susceptible to variation and to which there are exceptions. Consequently, speakers must account for alternation and both sources of non-conformity simultaneously. The experiment described in Chapter 3 tested speakers' intuitions as to the acceptability of variation in both alternating and exceptional segments.

1.3 Theoretical Framework: Optimality Theory

In this dissertation, analyses are couched in the Optimality Theory (OT) framework (Prince & Smolensky 1993). In OT, a constraint-based model of grammar, the well-formedness of possible output (or surface) forms is determined by the ranking of violable constraints. The constraints are universal, with different grammars arising from different rankings of these constraints.

There are three main components in the OT system: GEN, CON, and EVAL. In GEN a set of outputs is generated from a given input (or underlying representation), producing an exhaustive set of candidates for evaluation. GEN is capable of generating an infinite number of candidates, including ones which are identical to the input, slightly different from it, or seemingly unrelated to it. The only restriction is that the candidates must be composed of universal elements (e.g. prosodic and segmental structures).

CON is comprised of a set of violable, universal constraints. Although these constraints are fixed across languages, different rankings give rise to individual grammars. Constraints fall into one of two categories: markedness and faithfulness. While well-formedness is determined by markedness constraints, faithfulness constraints favor candidates that most closely correspond to the input (McCarthy & Prince 1995).

The surface representation, or *optimal candidate*, for each input is determined by EVAL, the mechanism by which the generated candidates are evaluated against the constraint ranking in the grammar, or language particular ranking of constraints. Candidates violating higher ranked constraints are eliminated, and the optimal candidate is selected once all others have violated the dominating constraints or more egregiously violated them. In Figure 1 is a schema of the architecture of OT (McCarthy 2002).

Figure 1. Basic architecture of an OT grammar

Input ➜ [GEN] ➜ candidates ➜ [EVAL] ➜ output

Consider a hypothetical grammar in which CON consists of three constraints, CONSTRAINT 1, CONSTRAINT 2 and CONSTRAINT 3. The constraints are strictly ranked with CONSTRAINT 1 dominating CONSTRAINT 2, which in turn dominates CONSTRAINT 3.[2] In this grammar, four candidates (Candidate a, Candidate b, Candidate c, Candidate d) are generated by GEN from a given input. The tableau in Table 2 illustrates the evaluation of the four candidates given the ranking of the three constraints. In the tableau, constraints are listed in columns in ranking order from left to right, with the highest-ranked constraint in the left-most column. An asterisk (*) denotes a violation of a specific constraint. An asterisk followed by an exclamation point (!) denotes a fatal violation and the elimination of the candidate in question. The pointing hand (☞) denotes the winning candidate for a given evaluation.

Table 2. CONSTRAINT 1 » CONSTRAINT 2 » CONSTRAINT 3

/input/	CONSTRAINT 1	CONSTRAINT 2	CONSTRAINT 3	CONSTRAINT 4
☞a. Candidate a		*		**
b. Candidate b		**!		
c. Candidate c		*	*!	
d. Candidate d	*!			

Let us take a look at the evaluation of the candidates in the tableau above. Although it incurs the least number of violations, Candidate d is first to be eliminated due to its violation of the highly-ranked CONSTRAINT 1. Candidate b is eliminated next since it incurs multiple violations of CONSTRAINT 2, a constraint violated only once by

[2] Constraint domination is denoted by '»', with the dominating constraint to the left of the arrows.

Candidates a and c. Finally, Candidate c is eliminated due to its violation of CONSTRAINT 3, a constraint which Candidate a (the only candidate left) does not violate. Since all constraints are violable, it is often the case that a winning candidate incurs violations of some constraints. However, as illustrated above, it must not incur more violations than any of the other candidates prior to their elimination from the evaluation.

There are two important principles in OT relevant to the work presented in this dissertation. The first, *Richness of the Base* (Prince & Smolensky 1993), prohibits constraints on the input level. This follows from the idea that constraint interaction and differences in the constraint hierarchy are what differentiate one grammar from another. Constraints are expressed as restrictions at the output level or as a correspondence relationship (faithfulness) between the input and output, but never as restrictions on the input. This means that, no matter what the input, the constraint ranking of a given language accounts for its grammatical forms and, more importantly, is able to prevent those forms that are unacceptable in that language from surfacing in the output. Although inputs in all languages are assumed to be the same, the principle of *Lexical Optimization* proposes that underlying forms posited by learners are those most harmonic with the output (Prince & Smolensky 1993, Inkelas 1994, Itô et al. 1995). According to Lexical Optimization, speakers are unlikely to select as the underlying representation a form containing some element that never surfaces in their grammar unless they are presented with evidence to this effect (i.e. through morphological alternation).

The analyses previewed in Chapter 2 and presented in Chapter 4 make use of classic OT (Prince & Smolensky 1993) to account for alternation, as well as two additional theoretical mechanisms – set-indexation and stochastic constraint rankings – to account for exceptionality and variation, respectively. I introduce these latter innovations in what follows.

1.4 Exceptions: Set-Indexation

Working within the framework of OT, I will account for exceptions through set-indexation. In this approach, exceptional elements are indexed to a set that does not conform to the general pattern in the grammar. This follows from the idea that, in the mental lexicon, exceptional elements of the grammar are marked because they do not follow some general pattern. In Pater (2000), words are indexed to a constraint that prevents them from following this general pattern. Pater (2005, 2006) extends this concept to morphemes. Exceptionality is accounted for by cloning an active constraint in the hierarchy and indexing it to the set of exceptional elements. The indexed constraint is then ranked higher than the original general constraint to prevent fatal violations of the general constraint by exceptional forms.

Exceptional indexation is illustrated in Table 3. The general pattern in this hypothetical language dictates that codas are disallowed. However there are some exceptional words that surface with a coda. The constraints involved in the regular pattern are NOCODA ('codas are not allowed') and MAX ('do not delete'). Coda deletion is achieved in [ba] by a ranking of NOCODA above MAX. To account for exceptional forms containing a coda, such as [dap], MAX is cloned and indexed to the set in which

/dap/ is a member (MAX$_1$). To ensure that coda deletion does not affect the members of this set, MAX$_1$ is ranked above NOCODA.

Table 3. Schema for exceptional indexing

input	output	MAX$_1$	NOCODA	MAX
bap	☞a. ba			*
	b. bap		*!	
bap+i	☞a. bapi			
	b. bai			*
dap$_1$	a. da	*!		*
	☞b. dap		*	
dap$_1$+i	☞a. dapi			
	b. dap	*!		

Based on my claim that exceptionality in Modern Hebrew spirantization is encoded at the segmental level, in Section 4.2.1, I propose an extension of Pater's set-indexation to the segment, allowing both alternating and exceptional segments to surface in hybrid roots and words.

1.5 Variation: Stochastic OT

The results of the experiment in Chapter 3 showed that variation is acceptable in Modern Hebrew spirantization. However, the degrees of acceptability of this variation differ depending on segment and context. To account for this, I use Stochastic OT and the Gradual Learning Algorithm (GLA) (Boersma 1998, Hayes & MacEachern 1998, Zuraw 2000, Boersma & Hayes 2001, Hayes & Londe 2006).

The GLA is an error-driven learner in which constraints are demoted or promoted after multiple learning trials based on probabilities and frequency in the input. During the learning of a word or utterance, constraints are assigned a ranking value. Then, depending on the constraint's proximity to other constraints in the hierarchy and its distribution's overlap with other constraints' distributions, the algorithm allows for different constraint rankings to arise during different learning trials. Variation is a function of these distinct rankings and the constraints' distributions.

The possibility of multiple output forms causes stochastic variation in the constraint ranking values, leading the algorithm to mimic the attested gradient frequency of variants in the language. An example of the ability of the GLA to mimic frequencies in the grammar is given in Table 4. In this example, from the pilot study described in Chapter 2, two forms of the word 'to bury' are compared. In the pilot, the expected form [likbor] was deemed acceptable 68.4% of the time, whereas the variant form [likvor] was acceptable 31.6% of the time. In the analysis, the variation between the two forms was achieved by reversing the relative ranking of the two context-free markedness constraints (*[+cont, -sib][3] and *STOP). In the grammar generated by the GLA, the ranking value for *[+cont, -sib] was such that it dominated *STOP 68.7% of the time, mimicking the gradience in the data.

Table 4. [likbor] (expected, *68.4%*) ~ [likvor] (variant, *31.6%*)[4]

*A. [likbor] = *[+cont, -sib] » *STOP (occurs 68.7% in grammar):*

/$k_1$br/ + inf. *'to bury'*	**IDENT-IO[cont]$_1$**	***V-STOP**	***[+cont, -sib]**	***STOP**	**IDENT-IO[cont]**
a. lik$_1$vor		*	*!	*	*
☞b. lik$_1$bor		*		**	

[3] The constraint *[+cont, -sib] is a markedness constraint prohibiting non-sibilant fricatives. For a discussion on the distinction between sibilants and non-sibilants, see Ladefoged (1997).
[4] Dotted lines in the tableaux indicate stochastic rankings of the two constraints on either side of the line.

*B. [likvor] = *STOP » *[+cont, -sib] (occurs 31.3% in grammar):*

/$k_1$br/ + inf. *'to bury'*	**IDENT-IO[cont]$_1$**	***V-STOP**	***STOP**	***[+cont, -sib]**	**IDENT-IO[cont]**
☞a. lik$_1$vor		*	*	*	*
b. lik$_1$bor		*	**!		

1.6 Overview of the Dissertation

Chapter 2 provides an overview of Modern Hebrew spirantization. In Section 2.1, I outline the phonemic inventory of Modern Hebrew and discuss templatic morphology as it applies to the language. I then provide a detailed description of Modern Hebrew spirantization. Section 2.2 provides an overview of Tiberian Hebrew, the predecessor of Modern Hebrew, discussing the differences between spirantization in this variety and its modern counterpart. Section 2.3 presents diachronic sound changes in Hebrew, and 2.4 provide an explanation for exceptions in spirantization by relating these changes to non-conformity in Modern Hebrew. Section 2.5 summarizes Adam's (2002) account of variation in Modern Hebrew spirantization, which led to the pilot study discussed in Section 2.6. In Section 2.7, I provide a preview of the OT analysis of Modern Hebrew spirantization based on the results of the pilot study.

Chapter 3 details a rating task in which participants were asked to rate the acceptability of variation in alternating and exceptional segments in Modern Hebrew spirantization. In Section 3.1, I discuss the goals and hypotheses for the study based on previously attested accounts and the preliminary analysis provided in Chapter 2. The methodology used for the experiment is outlined in Section 3.2 and the results, showing that although variation is indeed acceptable (and more so in alternating segments than it is in exceptional segments) are discussed in Section 3.3.

In Chapter 4, I present an OT analysis of exceptionality and variation by combining segmental-level set-indexation with stochastic OT. Section 4.1 summarizes the analysis of alternation in Modern Hebrew spirantization. In Section 4.2, I propose extending Pater's (2000) set-indexation approach to the segmental level to account for exceptional segments, and show how two alternate approaches are unable to handle the Modern Hebrew data. The Gradual Learning Algorithm and stochastic OT are discussed in Section 4.3 as a way of accounting for variation (Boersma 1998, Hayes & MacEachern 1998, Zuraw 2000, Boersma & Hayes 2001, Hayes & Londe 2006). In Section 4.4, I provide the final analysis, combining segmental-level set-indexation and stochastic constraint ranking to account for the results of the experiment described in Chapter 3.

In Chapter 5, I discuss several issues having to do with the learnability of non-conformity. Section 5.1 provides an overview of the acquisition of indexation. Section 5.2 outlines previous applications of set-indexation at the word and morpheme levels (Pater 2000, 2005), and its extension to the segmental level (as described in Chapter 4). Section 5.3 discusses the acquisition of two patterns of non-conformity in a single grammar, and poses questions for further development of learning algorithms to handle these.

2 Modern Hebrew Spirantization

In this dissertation, I investigate how exceptionality and variation can be integrated when these two sources of non-conformity occur in a single phonological system. In Modern Hebrew, we find that, due to historical mergers and more recent borrowings, there are many exceptions to the spirantization distribution. Additionally, those sounds that do spirantize exhibit variation at different levels. This results in a single phenomenon rich in both sources of non-conformity.

In this chapter, I describe the different aspects of Modern Hebrew spirantization, and provide a preliminary analysis of this phenomenon based on a pilot study. This serves as background for the design of an experimental rating task testing the acceptability of variation in Modern Hebrew spirantization, which I describe in Chapter 3. The results of that study, along with the preliminary analysis in this chapter, shape the final analysis proposed in Chapter 4.

This chapter is chiefly concerned with establishing a preliminary description of Modern Hebrew spirantization and the nature of non-conformity to the spirantization distribution. I therefore explore the allophonic distribution itself, exceptions, and variation. Based on the results of a pilot study on the acceptability of variation, I will identify questions for an experimental study of non-conformity in Modern Hebrew spirantization, to be taken up in Chapter 3.

In Section 2.1, I provide an overview of Modern Hebrew and introduce the spirantization distribution, as well as cases of exceptionality and variation. Following a summary of phonological descriptions from Tiberian Hebrew in Section 2.2, I relate these to diachronic changes in Hebrew and exceptionality in Modern Hebrew spirantization in Sections 2.3 and 2.4. In Section 2.5, I introduce variation in Modern Hebrew spirantization, followed in Section 2.6 by a pilot study investigating its nature. In Section 2.7, I propose an initial Optimality Theoretic analysis of Modern Hebrew spirantization, accounting for alternation using an analysis of allophony with constraints that refer to a segment's continuancy. I then propose an expansion of Pater's (2000) set-based approach to the segmental level to account for exceptionality, and stochastic constraint rankings for variation (Boersma 1998, Hayes & MacEachern 1998, Zuraw 2000, Boersma & Hayes 2001, Hayes & Londe 2006) .

2.1 Modern Hebrew

2.1.1 Language Background

Hebrew is classified as a Canaanite language and is a member of the Northwestern Semitic language branch of the Semitic family tree. Although its roots are documented as early as Biblical times, Hebrew was not spoken as a native tongue between 200 AD and the latter part of the 19th century, when it was revived in Europe and present-day Israel. Although the gap between Modern Hebrew and its ancestor, Biblical Hebrew, spans nearly eighteen centuries, Biblical Hebrew is believed to have had the greatest influence on most aspects of Modern Hebrew (Ravid 1995).

The term 'Modern Hebrew' refers to the variety of Hebrew spoken by children born in Israel since the Jewish people arrived in Israel at the end of the 19th century.

Since the inception of the idea to create a Jewish state in Israel, immigrants from many parts of the world have settled there. The languages spoken by these immigrants, spanning from Semitic to Indo-European languages, have had a great influence on many aspects of the different varieties of Hebrew currently spoken in Israel (Adam 2002).

Currently, there are two main varieties of Hebrew spoken in Israel, Oriental and non-Oriental. These varieties are mostly distinguishable in their phonology, the Oriental variety having the pharyngeals [ħ] and [ʕ], and the non-Oriental variety lacking them. Normative Hebrew, used mostly in news broadcasts and formal contexts, also has the pharyngeals, which have merged with other sounds in the non-Oriental variety (Adam 2002). In this dissertation, I use the term 'Modern Hebrew' to refer to the non-Oriental colloquial variety.

2.1.2 Phonemic Inventory

The phonemic inventory of Modern Hebrew appears in Table 5. Segments not found in the inventory for this variety are the pharyngeals /ħ/ and /ʕ/, which occur only in the Oriental variety (Adam 2002).

Table 5. Phonemic inventory of Modern Hebrew

	Bilabial	Labio-dental	Alveolar	Post-alveolar	Palatal	Velar	Uvular	Glottal
Stop	/p/ /b/		/t/ /d/			/k/ /g/		/ʔ/
Nasal	/m/		/n/					
Fricative		/f/ /v/	/s/ /z/	/ʃ/			/χ/	/h/
Affricate			/t͡s/					
Approximant					/j/		/ʀ/	
Lat. Approximant			/l/					

Noteworthy for this work is the distribution of supralaryngeal stops. In Modern Hebrew, three stops, /p/, /b/, and /k/ alternate with the fricatives [f], [v], and [χ] in a spirantization process while /d/, /t/, and /g/ do not. Tiberian Hebrew had a larger inventory of stops and fricatives, but many of the sounds have merged in the Modern variety. This is relevant to the present work, as it will explain the origins of many of the exceptional, non-alternating consonants in Modern Hebrew. This is discussed further in Section 2.2.

2.1.3 Templatic Morphology in Hebrew

As with most Semitic languages, words in most closed classes in Modern Hebrew are derived by the addition of vowels and affixes to consonantal roots (Berman 1978). Semantically related words often share a consonantal root, regardless of their lexical category. An example of a root /gdl/ (*'grow'*, *'large'*), one paradigm of its verbal inflections (for the binyan paʔal), and some semantically related words are in Table 6.

Table 6. Different lexical items for the root /**gdl**/

Binyan paʔal - 'to grow'

Past	Singular	Plural
1st	[**g**a'**d**a**l**ti]	[**g**a'**d**a**l**nu]
2nd masc	[**g**a'**d**a**l**ta]	[**g**a'**d**a**l**tem]
2nd fem	[**g**a'**d**a**l**t]	[**g**a'**d**a**l**ten]
3rd masc	[**g**a'**d**a**l**]	[**g**a**d**'**l**u]
3rd fem	[**g**a**d**'**l**a]	

Present	Singular	Plural
masculine	[**g**o'**d**e**l**]	[**g**o**d**'**l**im]
feminine	[**g**o'**d**e**l**et]	[**g**o**d**'**l**ot]

Future	Singular	Plural
1st	[e**g**'**d**a**l**]	[ni**g**'**d**a**l**]
2nd masc	[ti**g**'**d**a**l**]	[ti**gd**e'**l**u]
2nd fem	[ti**gd**e'**l**i]	
3rd masc	[ji**g**'**d**a**l**]	[ji**gd**e'**l**u]
3rd fem	[ti**g**'**d**a**l**]	

nouns: ['**g**o**d**e**l**] 'size', [**g**i'**d**u**l**] 'growth, tumor'
adjective: [**g**a'**d**o**l**] 'big'

Verbal and nominal patterns are relatively systematic with several conjugation constructions for each. Verbal paradigms have seven conjugation constructions, or *binyanim*, in Hebrew.[5] These are more regular and robust than the nominal constructions, or *mishkalim*; once a verb is borrowed into the language, it conforms to one of the binyanim, whereas new nouns can maintain their borrowed form and not match any of the native mishkalim (Bat-El 1994). An example of this is the borrowing of the English word *flirt*. In its nominal form, it preserves its original phonemic structure from English and does not conform to any of the Hebrew mishkalim, with both an initial and final consonant cluster. However, as a verb, it is modified to conform to one of the binyanim

[5] See Appendix B for a complete listing of *binyanim* and their different inflections.

(p**i**ʔ**e**l) as [fl**i**rt**e**t]. Due to the regular conformity of verbs with the conjugations constructions, only verbal paradigms will be examined in this dissertation.

2.1.4 Spirantization in Modern Hebrew

Spirantization is a lenition process by which stops become continuants (Kirchner 1998, González 2003, Kirchner 2004).[6] In Modern Hebrew, spirantization is triggered by a preceding vowel (Adam 2002). Participating in the alternation are the labial stops /p/ and /b/ and the voiceless velar /k/ with fricative alternants occurring in post-vocalic context and stops occurring elsewhere. I refer to this alternation between the stops and fricatives as the spirantization distribution of Modern Hebrew. Examples are provided in (5).

(5) Examples of the spirantization distribution in Modern Hebrew

	Root	3rd Person Sg. Past	Infinitive	
/p/ → [f]	/**p**rs/	[**p**aras]	[li**f**ros]	'to spread'
/b/ → [v]	/**b**nh/	[**b**ana]	[li**v**not]	'to build'
/k/ → [χ]	/**k**tb/	[**k**atav]	[li**χ**tov]	'to write'

In Modern Hebrew morphology, verbal paradigms are constructed by adding inflectional affixes to (mostly triconsonantal) roots. The examples of the spirantization distribution provided in (5) include cases where /p/, /b/, or /k/ occur in root-initial position. These consonants are word-initial and, thus, are realized as stops in the third person singular past forms. In the infinitive forms, inflectional prefixation results in a

[6] Cf. Baković (1994) for other views about spirantization as fortition.

vowel preceding the root-initial stop, causing the consonants to spirantize, surfacing as fricatives. In Table 7, I provide examples of the spirantization distribution in different positions in the root and in verbal inflectional paradigms.

Table 7. Spirantization distribution in verbal paradigms containing /p/, /b/, and /k/

Consonant Pair	**Root**	**Past**	**Infinitive or Future**	**Gloss**
/p/ → [f]	/**p**rs/	[**p**aras]	[li**f**ros]	*'spread'*
	/s**p**r/	[sa**f**ar]	[lis**p**or]	*'count'*
	/nʃ**p**/	[naʃ**af**]	[linʃ**of**]	*'exhale'*
/b/ → [v]	/**b**nh/	[**b**ana]	[li**v**not]	*'build'*
	/s**b**l/	[sa**v**al]	[lis**b**ol]	*'suffer'*
	/gn**b**/	[gana**v**]	[ligno**v**]	*'steal'*
/k/ → [χ]	/**k**tb/	[**k**atav]	[li**χ**tov]	*'write'*
	/m**k**r/	[ma**χ**ar]	[lim**k**or]	*'sell'*
	/dr**k**/	[dara**χ**]	[lidro**χ**]	*'step'*

The spirantization distribution in Modern Hebrew only applies to three of the six supralaryngeal stops; /t/, /d/, and /g/ do not spirantize. Historically, all non-emphatic stops[7] underwent spirantization in Tiberian Hebrew. Understanding these non-alternating stops requires some background on their origins in Tiberian Hebrew, which I discuss in the following section.

[7] /ṭ/ and /q/ were the two emphatic stops in Tiberian Hebrew, pronounced with a secondary pharyngeal pronunciation.

2.2 Tiberian Hebrew

The most recent book in the Old Testament was written in the third century BC. Only inferences can be made about the exact pronunciation of the form of Hebrew spoken at the time because it survives solely in written form, and its orthography contained mostly consonants. Around the ninth century AD, the Masoretic scholar community in Tiberias annotated the Biblical text with vocalization symbols, according to what they believed to have been the pronunciation in Biblical times. Tiberian Hebrew or Masoretic Hebrew, therefore, refers to this systematic vocalization of Biblical Hebrew.

The phonemic inventory of Tiberian Hebrew in Table 8 provides insights into the nature of some of the changes which have taken place in Hebrew over time (Prince 1975). An explanation of the nature of segments no longer found in Hebrew appears in Section 2.3.

Table 8. Phonemic Inventory of Tiberian Hebrew

	Bilabial	**Alveolar**	**Post-alveolar**	**Palatal**	**Velar**	**Uvular**	**Pharyngeal**	**Glottal**
Stop	/p/ /b/	/t/ /d/	/ṭ/		/k/ /g/	/q/		/ʔ/
Nasal	/m/	/n/						
Fricative		/s/ /z/	/ṣ/ /ʃ/				/ħ/	/h/
Affricate		/t͡s/						
Approximant	/w/	/r/		/j/			/ʕ/	
Lat. Approximant		/l/						

Unlike the non-Oriental variety of Modern Hebrew, the phonemic inventory of Tiberian Hebrew included the pharyngeal sounds /ħ/ and /ʕ/. In non-Oriental Modern Hebrew, however, /ħ/ and /ʕ/ have merged with [χ] (the fricative allophone of /k/) and /ʔ/, respectively. Also found in Tiberian Hebrew were the emphatics /ṭ/, /ṣ/, and /q/, which have merged with non-emphatic /t/, /s/, and /k/, respectively, in Modern Hebrew.

2.2.1 Spirantization in Tiberian Hebrew

Historically, spirantization in Modern Hebrew originated from the same phenomenon in Tiberian Hebrew. Unlike in Modern Hebrew, however, in Tiberian Hebrew the set of stops undergoing spirantization was not as limited: all non-emphatic singleton stops underwent spirantization, being realized as fricatives when they occurred in post-vocalic position. The distribution of stops and their fricative counterparts in Tiberian Hebrew is illustrated in (6) (Adam 2002).

(6) Stop/fricative alternation in Tiberian Hebrew

p/ɸ, t/θ	[paaθaħ]	'opened'	[jiɸtaħ]	'will open'
k/x, b/β	[kaaβaʃ]	'conquered'	[jixboʃ]	'will conquer'
g/ɣ, d/ð	[gaaðal]	'grew'	[jiɣdal]	'will grow'

Unlike the singleton stops in (6), the geminated stops ([pp], [bb], and [kk]) and the emphatic stops (/ṭ/ and /q/) did not undergo spirantization (Malone 1993). Additionally, the continuants /w/ and /ħ/ did not alternate with any stops in Tiberian

Hebrew. Their exemption from spirantization, followed by their historic neutralization, has resulted in acoustically identical segments that behave differently with respect to spirantization in Modern Hebrew. In the next section, I describe the diachronic changes that led to this divergence in behavior. In Table 9, we see some examples of non-alternation in Tiberian Hebrew leading to non-alternation in its Modern descendant.

Table 9. Non-alternating segments in Tiberian and Modern Hebrew

Non-alternation in Tiberian Hebrew			**Non-alternation in Modern Hebrew**			**Gloss**
/**q**/	[**q**ijem]	[le**q**ajem]	/**k**/	[**k**ijem]	[le**k**ajem]	'to fulfill'
/**w**/	[**w**iter]	[le**w**ater]	/**v**/	[**v**iter]	[le**v**ater]	'to concede'
/**ħ**/	[**ħ**alam]	[la**ħ**alom]	/**χ**/	[**χ**alam]	[la**χ**lom]	'to dream'

2.3 Diachronic Changes in Hebrew

A comparison of the phonemic inventories of Tiberian Hebrew and Modern Hebrew provides evidence of the diachronic loss of several segments. It is believed that most of the Tiberian Hebrew singleton segments that are absent from Modern Hebrew have merged with similar segments at some point in history (Bolozky 1980). The simplification of Tiberian Hebrew geminates into singleton segments is also a significant diachronic change for spirantization. In Modern Hebrew, the pronunciation of these degeminated segments is indistinguishable from singleton stops, resulting in acoustically identical segments, some of which alternate according to the spirantization distribution and others which do not, deeming them exceptional in post-vocalic context.

These mergers and simplifications have led to the presence of many exceptions to Modern Hebrew spirantization. The segments not found in Modern Hebrew are the pharyngeals /ħ/ and /ʕ/ (which have merged with /χ/ and /ʔ/, respectively), the emphatics /q/, /ṣ/, and /ṭ/ (which have merged with /k/, /s/, and /t/, respectively), and the glide /w/ (which has merged with /v/). These developments are illustrated in Table 10.

Table 10. Diachronic Changes from Tiberian to Modern Hebrew [8]

/w/ and [v] → /v/	[levater]	'to dissect'
	[levater] (< *w)	'to concede'
/ħ/ and [x] → /χ/	[maχar]	'sold' (masc.sg.)
	[maχar] (< *ħ)	'tomorrow'
/q/ and [k] → /k/	[kol]	'every'
	[kol] (< *q)	'voice'
/ṣ/ and /s/ → /s/	[sar]	'minister'
	[sar] (< *ṣ)	'turn away'
/ṭ/ and /t/ → /t/	[tovʕim]	'drowning' (pl.)
	[tovim] (< *ṭ)	'good' (masc.pl)
/ʔ/ and /ʕ/ → /ʔ/	[ʔal]	'don't'
	[ʔal] (< *ʕ)	'above'

Some of the changes in Table 10 involve fricatives and stops which normally participate in the spirantization distribution in Modern Hebrew. These obstruents are the contributors to exceptionality, as they fail to conform to the spirantization distribution in Modern Hebrew.

[8] Sounds to the right of the arrow in Table 10 represent phonemes of Modern Hebrew. Those to the left represent phonemes and allophones of Tiberian Hebrew.

2.4 Exceptionality in Modern Hebrew Spirantization

As mentioned in Section 2.1.3, spirantization in Modern Hebrew only involves /p/, /b/, and /k/ and their fricative counterparts [f], [v], and [χ]. Importantly, only the occurrences of these consonants that are derived from historically alternating Tiberian Hebrew consonants participate in the spirantization distribution in Modern Hebrew. Exceptions to spirantization in Modern Hebrew, then, are those consonants that do not alternate in accordance with the spirantization distribution. In this section I, provide an overview of the origin of non-alternating, exceptional segments in Modern Hebrew.

The uvular /q/ in Tiberian Hebrew was classified as an emphatic sound. This classification, associated with sounds in several other Semitic languages, describes a dorsal gesture that is coproduced with the consonant's primary articulation (Crystal 2003). Stop realizations of the sounds that corresponded to /q/ and /k/ in Tiberian Hebrew are phonetically identical in Modern Hebrew; both are [k]. However, they continue to behave differently in the language's phonology. In Modern Hebrew, instances of [k] that correspond to Tiberian Hebrew /k/ participate in spirantization, whereas those that correspond to Tiberian Hebrew /q/ do not. This is illustrated in (7).

(7) Spirantizing and non-alternating /k/ in Modern Hebrew

		Root	**3rd Person Sg. Past**	**Infinitive**	
a.	/k/ (< *k)	/**k**tb/	[**k**atav]	[li**χ**tov]	'to write'
b.	/k/ (< *q)	/**k**rʔ/	[**k**ara]	[li**k**ro]	'to read'

Tiberian Hebrew /ħ/ and /w/ have merged with /χ/ and /v/, respectively, in Modern Hebrew, and the present-day fricatives that trace back to /ħ/ and /w/ are exceptional with respect to the spirantization distribution, because they do not alternate. As was the case with /k/, the merger of the continuants has resulted in entire paradigms with velar and labial fricatives that do not alternate with stops (from the historically non-alternating /ħ/ and /w/), standing alongside others with velar and labial obstruents that alternate according to the dictates of the spirantization distribution (from historically alternating /k/ or /b/). The former include the pairs in part (a.) of (8) which display the fricative not only in post-vocalic position, as expected, but also in word-initial position. In part (b.) of (8), we see cases of /χ/ and /v/ which do alternate (in accordance with the spirantization distribution) with /k/ and /b/, respectively. Although spirantization is usually regarded as a weakening process that stops undergo, in my description of the spirantization distribution I regard it as an allophonic alternation between the stops /p/, /b/, and /k/ and the fricatives [f], [v], and [χ]. For this reason, I consider non-alternating fricatives to be exceptions to the spirantization distribution when they occur in non-post-vocalic postion.

(8) Alternating and non-alternating /χ/ and /v/ in Modern Hebrew

		Root	3rd Person Sg. Past	Infinitive	
a.	/v/ (<* w)	/**v**tr/	[**v**iter]	[le**v**ater]	‘to give up’
	/χ/ (<* ħ)	/**χ**ps/	[**χ**ipes]	[le**χ**apes]	‘to look for’
b.	[v] (<* b)	/**b**tl/	[**b**itel]	[le**v**atel]	‘to cancel’
	[χ] (<* k)	/**k**pr/	[**k**iper]	[le**χ**aper]	‘to atone’

In Modern Hebrew, there exists a phoneme /f/ which did not exist in Tiberian Hebrew. This segment occurs in words borrowed from other Semitic languages, as well as from Germanic and Slavic languages, that have become lexicalized (Idsardi 1997). When words with this segment were borrowed, they were not made to conform to the phonology of the language, which disallows non-post-vocalic [f]. The result is a non-alternating [f], as seen in (9).

(9) Alternating and exceptional /f/ in Modern Hebrew

		Root	3rd Person Sg. Past	Infinitive	
a.	/f/	/**f**ʃl/	[**f**iʃel]	[le**f**aʃel]	'to mess up'
b.	[f] (<* p)	/**p**ʃt/	[**p**iʃet]	[le**f**aʃet]	'to simplify'

Recall from Section 2.2.1 that only singleton non-emphatic stops spirantized in Tiberian Hebrew. Geminate segments from Tiberian Hebrew have degeminated in Modern Hebrew, resulting in a singleton stop. However, these stops maintain their exceptionality with respect to spirantization in Modern Hebrew. In (10), exceptionality occurs in the form of instances of post-vocalic stops.

(10) Non-alternating stops (from Tiberian Hebrew geminates)

	Tiberian Hebrew	Gloss	Modern Hebrew
a.	[sipper]	'told'	[siper]
b.	[kippur]	'atonement'	[kipur]
c.	[nibbe]	'predicted'	[nibe]
d.	[ħabbala]	'sabotage'	[χabala]

In summary, of the six stop/fricative pairs which historically participated in spirantization, Modern Hebrew has only three alternating stop/fricative pairs: [b] and [v], [p] and [f], and [k] and [χ].[9] Due to historical change, non-alternating segments include the segment [k] whose origin is the emphatic [q] in Tiberian. The fricatives [f], [v], and [χ] are found in non-alternating paradigms in situations where historical mergers and borrowings have left their mark. Finally, historically degeminated [p], [b], and [k], now instantiated as singleton stops, obtain exceptional status in regard to spirantization by being realized as stops in all contexts.

2.4.1 Exceptionality at the segmental level

I argue that exceptionality in Modern Hebrew spirantization must be encoded at the segmental level, rather than at the lexical level or root level. The lack of alternation in these exceptional segments does not affect the distribution of other segments in a given paradigm. This is seen in Table 11 which presents words containing both an alternating segment (bolded) and a non-alternating segment (underlined) which is sometimes exceptional with respect to the spirantization distribution (Bolozky 1996). I will refer to such lexical items as 'hybrid' forms. Hybrid words demonstrate the need for the analysis of exceptionality to be at the segmental level. In Section 2.7.2, I examine the consequences of hybrid words for analyses that represent exceptionality at the level of the word.

[9] An analysis of the lack of participation of /t/, /d/, and /g/ in the spirantization distribution in Modern Hebrew is presented in Temkin Martínez (2005).

Table 11. Hybrid words with respect to spirantization in Modern Hebrew

Root	**Past (3p.sg.m)**	**Infinitive**	**Gloss**
C_1 alternates, C_2 is non-alternating			
/**b**χn/	[**b**aχan]	[li**v**χon]	‘examine’
/**b**k̲r/	[**b**ik̲er]	[le**v**ak̲er]	‘visit’
/**k**b̲d/	[**k**ib̲ed]	[le**χ**ab̲ed]	‘honor’
/**k**b̲h/	[**k**ib̲ah]	[le**χ**ab̲ot]	‘extinguish’
/**p**χd/	[**p**aχad]	[leha**f**χid]	‘fear, scare’
C_1 is non-alternating, C_2 alternates			
/k̲**b**r/	[k̲a**v**ar]	[lik̲**b**or]	‘bury’
/k̲**p**ʔ/	[k̲a**f**a]	[lik̲**p**o]	‘freeze’
/χ**p**r/	[χa**f**ar]	[laχ**p**or]	‘dig’

In addition to the non-alternating, exceptional segments described in this section, the alternating pairs ([p]/[f], [b]/[v], and [k]/[χ]) have been reported to show variation in colloquial speech (Adam 2002). Like exceptional segments, these cases of variation are instantiated as stops in post-vocalic context and fricatives elsewhere. Unlike exceptional segments, though, the variation occurs in segments and paradigms that normally do conform to the spirantization distribution. Section 2.5 outlines this variation and Section 2.6 describes a pilot study designed to verify its existence.

2.5 Variation in Modern Hebrew Spirantization

As documented in Adam (2002), variation in Modern Hebrew spirantization occurs when segments that usually alternate according to the dictates of the spirantization distribution are produced on occasion with the opposite continuancy value to what the distribution would predict. Table 12 lists all of the cases of variation discussed by Adam.

According to her findings, the possibility of variation is sensitive to the place of articulation of the consonants and its position in the word. In word-initial position, variation occurs in all three spirantizing segments, /p/, /b/, and /k/, with the fricatives [f], [v], and [χ], respectively, as acceptable variant forms. In post-consonantal context, however, only the labial variants [f] and [v] occur and not [χ], while in post-vocalic context only the velar variant [k] occurs and not the labials [p] or [b].

Table 12. Variation in Modern Hebrew spirantization (Adam 2002)

Expected	**Acceptable Variation**	**Gloss**
Word-initial Position:		
pizer	**f**izer	'scattered'
bikeʃ	**v**ikeʃ	'asked for'
pagaʃ	**f**agaʃ	'met'
baχar	**v**aχar	'chose'
kibes	**χ**ibes	'laundered'
kisa	**χ**isa	'covered'
Post-consonantal Position:		
jid**p**ok (archaic)	jid**f**ok	'will knock'
jik**b**or	jik**v**or	'will bury'
Post-vocalic Position:		
je**χ**abes	je**k**abes	'will launder'
je**χ**ase	je**k**ase	'will cover'

In order to gather more detailed information about the scope and nature of the variation with respect to spirantization in Modern Hebrew, a pilot acceptability rating task was conducted to collect data regarding the acceptability of variation in words containing /b/, /p/, and /k/ including those in the list above.

2.6 Pilot Study: Variation and Alternation

The pilot study discussed in this section was designed to elicit the judgments of native Hebrew speakers concerning the acceptability of variation in segments that normally spirantize in Modern Hebrew. Participants were asked to listen to a series of sentences containing words with the *expected* or *variant* pronunciation (behaving in line with or in opposition to the spirantization distribution, respectively) and rate the acceptability of the target word.

Participants' ratings of the utterances are the dependent variable for this experiment. The independent variables were the position of the segment in question (word-initial, post-vocalic, or post-consonantal) and consonant pairs (p/f, b/v, or k/χ).

Based on Adam's (2002) description of variation, the following predictions were made. I predicted that there would be variation (i.e. that variant forms would be rated at least somewhat acceptable), but lack of free variation (i.e. it was predicted that the expected and variant forms would receive different ratings). Furthermore, a preference was predicted for the expected forms over their variant counterparts. Additionally, I expected an interaction between the variables of position and consonant pair, based on Adam's observation.

2.6.1 Stimuli

Tri-consonantal roots, including those in Table 12 for which variation was reported by Adam (2002), were selected with /b/, /p/, and /k/ occurring in either root-initial or root-medial position. Four roots were selected for each of the three target segments—two with the segment root-initial and two with it root-medial. Next, each of these roots was conjugated for both masculine and feminine gender as well as past and future tense, yielding four stimuli for each root. Using an Olympus DM-10 digital recorder, the 48 target words, embedded in a carrier sentence, were recorded by a female native speaker of Modern Hebrew in both the expected form (consistent with spirantization distribution) and the variant form (with the opposite continuancy value for the consonant in question), resulting in a total of 96 stimulus sentences for the perception experiment. To keep the experiment under 30 minutes, the stimuli were divided into two randomized lists, each containing 48 sentences. Each of the two lists contained half of the stimuli for each of the roots used, with matching expected and variant forms. In Table 13 I include a sample division of stimuli for a single root into the two participant lists, with each list containing either the feminine or masculine forms.

Table 13. Sample conjugation for a single root and its division into two lists

Expected		**Variant**		**Gloss**
kibes	(list A)	**χ**ibes	(list A)	'laundered' (m.)
kibsa	(list B)	**χ**ibsa	(list B)	'laundered' (f.)
je**χ**abes	(list B)	je**k**abes	(list B)	'will launder' (m.)
te**χ**abes	(list A)	te**k**abes	(list A)	'will launder' (f.)

One of the two lists was randomly selected for each of the subjects. Due to a labeling error, 10 tokens were excluded from each of the experiments. The final distribution of the stimuli for each list is summarized in Table 14. Note that the error resulted in the absence of all stimuli with the velars in post-consonantal position and half of the stimuli with velars in post-vocalic position. For a full list of the stimuli, see Appendix D.

Table 14. Distribution of stimuli

Context	k/χ	p/f	b/v
Word-initial	4	4	4
Post-vocalic	4	8	8
Post-consonantal	0	4	4

2.6.2 Participants

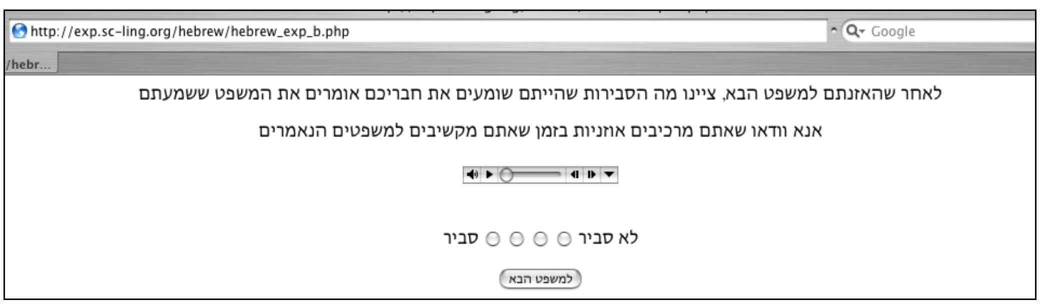
For this study, 26 native speakers of Modern Hebrew residing in Israel were recruited via email (19 females and 7 males). Their ages ranged from 21 to 60. The distribution resulted in 12 participants for list A and 14 for List B. One of the participants (from List A) was excluded from the analysis because she rated all utterances as either unlikely or highly unlikely.

2.6.3 Procedure

Before listening to and rating the stimuli, participants were asked to complete a biographical survey asking for their age, gender, first and home languages, and level of education. This information was used to ensure that all participants met the requirements for the study. Participants were then randomly assigned to hear one of the two lists described in Section 2.6.1. The entire experiment was conducted online and all experiment-related materials were in Hebrew.

During the experiment, participants were presented with the auditory stimuli and were asked to rate the likelihood that a peer would have said the sentence as it was provided in the experiment. In the rating task, participants had to select one of four radio buttons on the screen with the word meaning ‘likely’ at the left side of the button set and the words meaning ‘not likely’ at the right side of the button set, as shown in the screen shot in Figure 2. Participants could listen to each sentence an unlimited number of times before selecting a response, and they had the opportunity to change their response until they clicked on the ‘next’ button to move to the next sentence. The experiment was conducted online using a .php script authored by Ed Holsinger.

Figure 2. Screen shot of experiment window

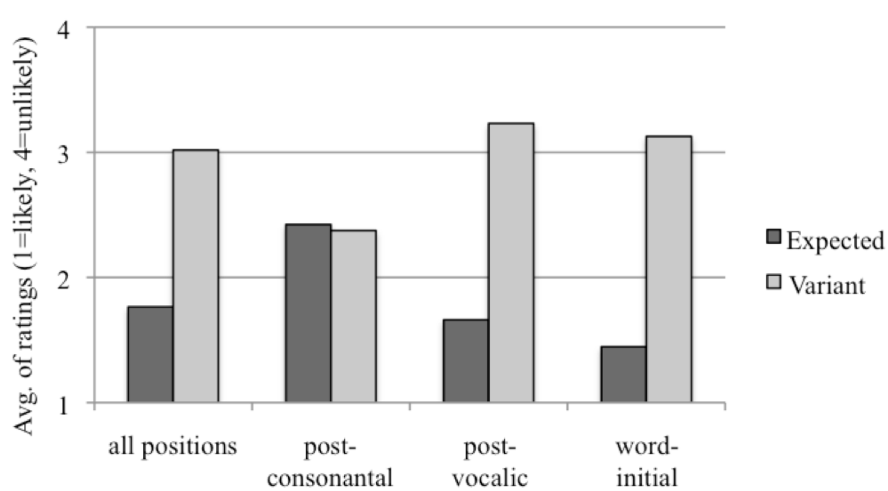


2.6.4 Results

Participants’ responses corresponding to the four radio buttons were recorded on a four-point scale. Selections of the leftmost button (closest to ‘likely’) received a score of one. Likewise, selections of the rightmost button (closest to ‘unlikely’) received a score of four. Selection of the second button from the left received a score of two, while the second button from the right received a score of three. As predicted, preliminary analyses across subjects revealed a preference for the expected form when the target segment occurred in word-initial context (as a stop) or in post-vocalic context (as a fricative). When the target segment occurred in post-consonantal context, however, there was a slight (not statistically significant) preference for the variant form (a fricative). Figure 3 shows the average ratings across participants by position.

Due to the lack of k/χ tokens in post-consonant position, the ANOVA analyses excluded k/χ pairs in all positions. A repeated-measures ANOVA revealed a main effect for both allophone, or whether a token's pronunciation was the expected or variant form, ($F_1(24) = 198.18$, $p < .001$) and consonant pair ($F_1(24) = 16.45$, $p < .001$) on the rating given within subjects. Furthermore, there was a significant interaction between consonant pair and allophone ($F_1(25) = 23.456$, $p < .001$).

Figure 3. Average of ratings by position



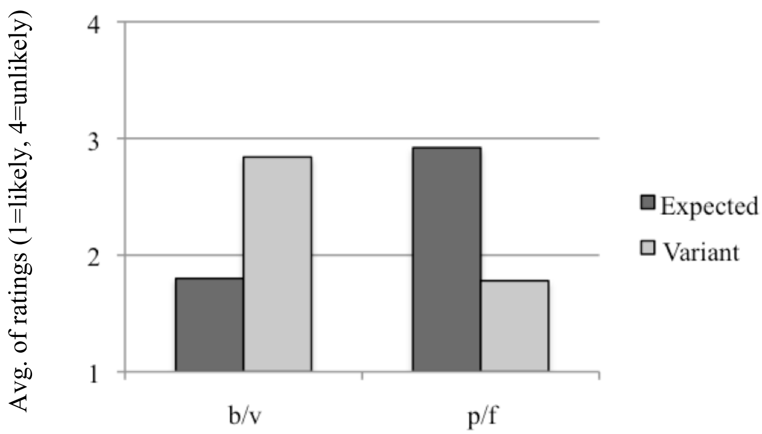
A univariate ANOVA for between-tokens revealed a main effect for allophone ($F_2(1) = 83.67$, $p < .001$), and two significant interactions: allophone and consonant pair ($F_2(2) = 10.529$, $p < .001$), and allophone and position ($F_2(2) = 26.219$, $p < .001$).

While the effect of allophone was predicted to be of importance, the effect of consonant pair in the labials is surprising and unattested.[10] A closer look within each position shows that while the different consonant pairs tended to behave similarly in post-vocalic and word-initial contexts, the labial consonant pairs acted quite differently in post-consonantal context .

As Figure 4 shows, subjects treated the consonant pairs p/f and b/v quite differently in terms of the acceptability of their expected and variant forms in post-consonantal context. While the b/v pairs seem to pattern with the general trend shown across positions in Figure 3, with the expected form being judged as more acceptable ($F_1(24) = -5.436$, $p < .001$), the opposite is true of the p/f pair ($F_1(24) = 5.035$, $p < .001$). It is this odd behavior of the p/f pair within post-consonantal position that leads to a main effect of consonant pairs.

[10] In fact, the analysis for variation in Adam (2002) groups both labial pairs and compares them to the velar k/χ pair.

Figure 4. Average of ratings for post-consonantal position by pair



A more detailed analysis of the individual consonant pairs in post-consonantal position shows that the apparent free variation in this position (seen in Figure 3) was actually due to combining these two opposing results. Paired *t*-tests comparing the ratings of the expected and variant forms of each of the two consonant pairs in this position show that the differences were statistically significant. Table 15 summarizes these results.

Table 15. Summary of statistical analysis by consonant pair in post-consonantal position.

Pair	***t***	**df**	***p***
b/v	-5.436	24	<.001
p/f	5.035	24	<.001

Paired *t*-tests were also performed comparing subjects' mean ratings of the expected versus variant tokens within each word position. These revealed that the expected tokens were judged significantly more acceptable in all but post-consonantal position, where the consonant pairs did not behave similarly. Table 16 provides the results of the *t*-tests.

Table 16. Summary for statistical analysis by position.

Environment	*t*	df	*p*
All	-10.641	25	<.001
Post-consonantal	.332	25	.743
Post-vocalic	-9.558	25	<.001
Word-initial	-10.806	25	<.001

In summary, the pilot study showed variation in the acceptability of the segments in question. As predicted, it was not the case that the expected and variant forms occurred in free variation. Rather, there was a preference for the expected segment in seven of the eight conditions, with subjects only showing preference for the variant form when the voiceless labial pair occurred in post-consonantal context. As for the prediction regarding the interaction of consonant pair and position, statistically significant differences were found, but in order to determine the nature of this significance, more information will have to be collected regarding the labial pairs in order to rule out lexical effects, and data for velars occurring in post-consonantal position must also be collected.

2.7 Preview: Analysis of Modern Hebrew Spirantization

This preliminary version of the analysis described in Chapter 4 provides some background for the design of the follow-up study described in the following chapter. As is evidenced by the data collected in the pilot study described in the previous sections, an analysis of Modern Hebrew spirantization must account not only for alternation and its variation, but also for cases of exceptionality. These three behaviors are outlined in Table 17.

Table 17. Alternation and non-conformity in Modern Hebrew spirantization

Non-Alternating Segments *(exceptionality)*	***Variation* of Alternating Segments**	**Alternating Segments *(allophony)***
[si**p**er], [lesa**p**er], [lis**p**or] 'to tell' and 'to count'	[**p**izer] ~ [**f**izer] 'to scatter'	[**p**aras], [li**f**ros] 'to spread'
[si**b**eχ], [lesa**b**eχ], [nis**b**aχ] 'to complicate'	[**b**ikeʃ] ~ [**v**ikeʃ] 'to ask for'	[**b**ana], [li**v**not] 'to build'
[**k**aʃar], [li**k**ʃor], [hit**k**aʃer] 'to tie' and 'to connect'	[**k**ibes] ~ [**χ**ibes] 'to launder'	[**k**atav], [li**χ**tov] 'to write'

In this section, I will first present the constraints needed to account for the allophonic spirantization distribution in Modern Hebrew. Next, I will provide an overview of a previous analysis of allophony and exceptionality. Then, following an introduction to lexical approaches to exceptionality and non-conformity, I will present an an analysis making use of set-indexation (Pater 2000) to capture segmental exceptions and using stochastic rankings (Boersma 1998, Hayes & MacEachern 1998, Zuraw 2000) to obtain variation.

2.7.1 Analysis of Alternation

In Optimality Theory (OT), an allophonic distribution results when a markedness constraint banning a segment or feature in a certain context dominates a context-free markedness constraint banning the opposite and both dominate the faithfulness constraint requiring its realization. In the analysis that I propose for Modern Hebrew spirantization, the relevant faithfulness constraint refers to the feature [continuant], and the relevant markedness constraints refer to the presence of stops in a particular segmental context as well as fricatives in general. Given Richness of the Base (Prince & Smolensky 1993), the ranking of these constraints must be capable of generating the attested allophonic distribution regardless of whether a stop or fricative appears in the input.

In the analysis of segments participating in the spirantization distribution, a central constraint is the one banning post-vocalic stops. I assume this constraint to be *V-STOP (Benua 1997, Kirchner 1998, González 2003), defined in (11). Since this contextual markedness constraint is what drives regular spirantization, it will be ranked above the relevant faithfulness constraint for [continuant].

(11) Context-sensitive markedness constraint [11]

***V-STOP** Post-vocalic stops are prohibited.

The context-free markedness constraints on the obstruent alternants are defined in (12). Although for cases of alternation only the markedness constraint against non-sibilant fricatives is needed, *STOP proves crucial for the analysis of variation.

[11] I use *V-Stop as it is formalized in the broader sense for all stops. Note, however, that /t/, /d/, and /g/ do not spirantize in Modern Hebrew. For an analysis of the lack of spirantization in these cases see Temkin Martínez (2005).

(12) Context-free markedness constraints (Benua 1997)

***[+cont, -sib]** Non-sibilant fricatives are prohibited.[12]

***STOP** Stops are prohibited.

A faithfulness constraint for the feature [continuant], though not required for the correct selection of the optimal candidate in the allophony cases, will be central to the analysis of exceptional segments. The ranking of all markedness constraints above IDENT-IO[cont] causes spirantization in alternating segments to be determined solely by markedness.

(13) Faithfulness constraint

IDENT-IO[cont] Let α be a segment in the input and β be a correspondent of α in the output. If α is [γcont], then β is [γcont] (McCarthy & Prince 1995).
"Input-output correspondents are identical in [±cont]."

The ranking of these constraints for the analysis of alternating segments is shown in (14) and its applications are illustrated in Table 18 and Table 19.

(14) Constraint ranking

***V-STOP » *[+cont, -sib] » IDENT-IO[cont], *STOP**

[12] See Ladefoged (1997) on the need to distinguish sibilants from other fricatives, as they are distinct in acoustic features across the world's languages.

The contextual markedness constraint is placed higher than the context-free markedness constraints in (12). The ranking *V-STOP » *[+cont, -sib] » *STOP produces a pattern in which fricatives occur in post-vocalic context and underlying stops occur in all other environments. More specifically, when it comes to the stops and fricatives in question, the ranking of *V-STOP » *[+cont, -sib] ensures that the output contains fricatives in post-vocalic context, and the ranking *[+cont, -sib] » *STOP ensures that stops are favored to occur elsewhere (namely, in word-initial and post-consonantal contexts). As mentioned above, the constraint *STOP, while not critical in the ranking for cases of alternation, will prove necessary for the analysis of variation, which I address in Section 2.7.3.

The fact that markedness dominates faithfulness ensures that the allophonic distribution of the stop/fricative pairs will be unaffected by the presence of either a stop or a fricative in the input. In the following tableaux, this is demonstrated for the consonants under focus through the use of fricatives in the input for output stops and stops in the input for output fricatives. These possible inputs are made available by Richness of the Base.

In post-vocalic context, spirantization-driving contextual markedness dominates the context-free markedness constraint for fricatives along with faithfulness for continuancy. As a result, post-vocalic stops are realized as fricatives, as seen for the first root consonant in Table 18.

Table 18. *V-STOP » *[+cont, -sib]

/**k**pr/ + (infinitive) *'to deny'*	*V-STOP	*[+cont, -sib]	IDENT-IO[cont]	*STOP
☞a. li**χ**por		*	*	*
b. li**k**por	*!			**

For stops to occur in word-initial and post-consonantal contexts, the markedness constraint against non-sibilant fricatives must be ranked higher than faithfulness for continuancy and higher than *STOP, leading to the absence of fricatives in post-consonantal context. This is demonstrated for the post-vocalic context by the second root consonant in Table 19. (The first root consonant here could be /k/ in the input, as in Table 18, and still map to the same output form, but it is the input-output mapping of the second root consonant with which we are concerned in this instance.)

Table 19. *[+cont, -sib] » IDENT-IO[cont]

/χ**f**r/ + (infinitive) *'to dig'*	*V-STOP	*[+cont, -sib]	IDENT-IO[cont]	*STOP
☞a. liχ**p**or		*	*	*
b. liχ**f**or		**!		

Likewise, the same ranking compels a stop realization in word-initial position, as seen in Table 20, with the first root consonant:

Table 20. *V-STOP » IDENT-IO[cont]

/χns/ + (3p.past) *'gathered'*	*V-STOP	*[+cont, -sib]	IDENT-IO[cont]	*STOP
☞a. **k**ines			*	*
b. **χ**ines		*!		

Although the above ranking captures the spirantization distribution to which alternating obstruents conform, in exceptional cases it does not select the correct candidate. In Table 21, we see that, due to the ranking of markedness over faithfulness, the candidate containing a stop in word-initial context or a fricative in post-vocalic context is wrongly selected (💣 denotes a wrongly selected candidate).

Table 21. Tableaux for exceptional, non-alternating segments

	***V-STOP**	***[+cont, -sib]**	**IDENT-IO[cont]**
A. /**v**tr/ + (3p.past) *'forgave'* (v <*w)			
a. **v**iter	*	*!	
💣b. **b**iter	*		*
B. /**χ**ps/+ (3p.past) *'looked for'* (χ <*ħ)			
a. **χ**ipes	*	*!	
💣b. **k**ipes	*		*
C. /s**p**r/+ infinitive *'to tell'* (p <*pp)			
a. lesa**p**er	*!		
💣b. lesa**f**er		*	*

Ranking faithfulness higher than the two markedness constraints in the tableau above would generate the correct output in the exceptional cases in Table 21. However, it would be problematic for the analysis of alternating segments shown in Table 19 and Table 20, predicting a contrastive distribution rather than allophony for continuancy in the consonants under focus.

In addition to the problem presented by the different and opposing rankings required for the analysis of individual words that contain alternating segments versus exceptional segments, an empirically adequate analysis for Modern Hebrew spirantization must also account for words where exceptional and alternating segments occur together in the same form, as in the hybrid words described in Section 2.4. Some examples are in Table 22, with exceptional segments underlined and alternating segments bolded.

Table 22. Examples of hybrids in Modern Hebrew

Root	**Past (3p.sg.m)**	**Infinitive**	**Gloss**
/**b**χn/	[**b**aχan]	[li**v**χon]	'examine'
/k̲**b**r/	[k̲a**v**ar]	[lik̲**b**or]	'bury'

These hybrid words reveal that the analysis cannot simply postulate a re-ranking of the constraints shown thus far for different words or sets of words, because the same word can display segments with opposite behaviors with respect to spirantization.

2.7.2 Analysis of Exceptionality

I turn now to introducing the analysis to account for the co-existence of alternating and exceptional segments. The literature addressing exceptionality at the word level predicts that entire words will behave either regularly or exceptionally with respect to a given phenomenon. Different mechanisms such as lexical tier and lexical set membership (Itô & Mester 1999, Pater 2000) have been used, achieving similar results for the most part. In this section, I first summarize Pater's (2000) set-based approach, which makes use of lexically indexed constraints. I then propose to extend set membership from words to segments. This section serves as a preview of the analysis which will later be developed in Chapter 4. This preview partially serves as a precursor to the experiment described in Chapter 3.

2.7.2.1 Lexically Indexed Constraints and Set-Indexation

Pater (2000) provides an analysis of lexical non-uniformity in English secondary stress. His account describes secondary stress patterns in derived forms as cases where (a) secondary stress always falls on the syllable containing the primary stress in the base stem, (b) secondary stress does not fall on the syllable containing the primary stress in the base stem due to its proximity to the syllable containing primary stress in the derived form, and (c) where secondary stress is variable. Examples of these three cases are in Table 23. The regular pattern for secondary stress assignment is seen in (a), where the secondary stress in *phònetícian* is assigned from the left and does not correspond to the primary stress in its stem *phonétic*. The exceptional pattern is seen in (b) where secondary stress in *accrèditátion* falls on the same syllable as the primary stress in its base stem, *accrédit*. Secondary stress is variable in (c), where both the exceptional pattern (*sègmèntátion*) and the regular pattern (*sègmentátion*) are acceptable.

Table 23. Secondary stress in English (Pater 2000)

Base stem		Derived form
a	phonétic	phònetícian
b	accrédit	accrèditátion
c	sègmént	sègmentátion ~ sègmèntátion

In set-indexation, exceptionality is treated as a whole-word phenomenon that emerges from the activity of constraints that reference particular sets of words. Pater proposes that words are encoded for set membership, and each set can have its own collection of set-specific constraints. General (i.e. not lexically set-specific) constraints can be ranked separately from their set-specific counterparts to allow the behavior of members of distinct sets to differ.

Pater brings these assumptions to bear on the problem of exceptionality in English stress. He assumes that stress is present in the input, with IDENT-STRESS requiring that the output correspondent of an underlyingly stressed syllable be stressed. An IDENT-STRESS constraint that is indexed to the set of words that preserve stem stress is ranked higher than the relevant markedness constraints, leading those words to show exceptionality to the usual pattern of secondary stress. This is illustrated in the tableaux in Table 24 where *'condensation'* (a.) is a member of the exceptional set S_1, and the word *'information'* (b.) is not. Other constraints used by Pater in this case are *CLASH-HEAD, which bans stressed syllables adjacent to the head syllable of the prosodic word, and ALIGN-L, which requires that all feet be aligned with the left edge of the prosodic word. In this case, then, the highly ranked lexically indexed faithfulness constraint IDENT-STRESS-S_1 is only applicable to candidates for those words belonging to that set (a in Table 24). The winning candidate in (a), then, is the output whose secondary stress corresponds to the primary stress of its base stem, *còndènsátion*. Words which do not belong to this set (b in Table 24) can only incur violation of the general constraints. Since the markedness constraint *CLASH-HEAD is ranked above the general IDENT-STRESS, markedness will select the candidate which follows the regular pattern for secondary stress assignment, *ìnformátion*.

Table 24. Tableaux illustrating set-based constraints from Pater (2000)

Output	ID-STRESS-S_1	*CLASH-HEAD	ID-STRESS	ALIGN-L
a. condénsation$_{(S1)}$				
i. [cònden][sá]tion	*!		*	
☞ii. [còn][dèn][sá]tion		*		
b. ìnfórmation				
☞i. [ìnfor][má]tion			*	
ii. [ìn][fòr][mátion]		*!		

To account for the set of words in which secondary stress is variable (as in Table 23), Pater proposes the use of a lexically indexed markedness constraint, *CLASH-HEAD-S_2, whose ranking with respect to PARSE-σ ('syllables are parsed by feet') is not fixed, predicting free variation between two given candidates. Also crucial to Pater's approach is the assumption that set membership is not necessarily identical from speaker to speaker, allowing for between-speaker variation.

Applying Pater's approach to Modern Hebrew spirantization, we are able to obtain exceptional forms with a lexically indexed faithfulness constraint, IDENT-IO[cont]$_1$, ranked higher than the relevant markedness constraints, and capture alternating forms with the general IDENT-IO[cont] ranked below them. The stochastic ranking of the relevant markedness constraints will then drive variation, as I will demonstrate in the following sections. In Figure 5, we see a schematized illustration of the rankings of the set-indexed constraints in Modern Hebrew spirantization.

Figure 5. Schema for exceptionality and alternation using set-based approach in Modern Hebrew spirantization

IDENT-IO[cont]$_1$ » Markedness constraints » IDENT-IO[cont]

*V-STOP,*STOP,*[+cont, -sib]

Prohibits alternation in exceptional segments	*Determines the distribution of stops and fricatives in alternating segments*

2.7.2.2 Extending Set-Indexation to the Segmental Level

In order to allow for exceptionality at multiple levels within a single model, I propose to extend lexically indexed set membership to the individual segments of a word. Set membership will be specified for each segment. Thus, in a language with a two-way split in behavior, exceptional segments will be specified as members of one set (e.g. '1') whereas alternating segments will be unspecified for set membership. In the case of

Modern Hebrew spirantization, variation occurs in segments that normally participate in the spirantization distribution (those that are unspecified for set membership, in this case), an issue to which I turn in the next section.

In Table 25 through Table 27, we see how the set analysis is applied to cases where there is either alternation or exceptionality with no variation. The tableaux in Table 25 represent lexical items with two alternating segments. Since these segments are not indexed for an exceptional set, the only faithfulness constraint applicable to them is the general IDENT-IO[cont], which is ranked below the relevant markedness constraints. This being the case, the ranking of the markedness constraints determines the winning candidates, with post-vocalic fricatives as well as word-initial and post-consonantal stops.

Table 25. Words containing two alternating segments

Input	Output	IDENT-IO[cont]$_1$	*V-STOP	*[+cont, -sib]	*STOP	IDENT-IO[cont]
/bkh/ + (inf.) *'to cry'*	☞a. livkot			*	**	*
	b. libkot		*!		***	
	c. livχot			**!	*	**
	d. libχot		*!	*	**	*
/bkh/ + (3p.past) *'cried'*	☞a. baχa			*	*	*
	b. baka		*!		**	
	c. vaχa			**!		**
	d. vaka		*!	*	*	*

The tableaux in Table 26 and Table 27 demonstrate that the set-indexed faithfulness constraint IDENT-IO[cont]$_1$ is crucially ranked above *V-STOP and

*[+cont, -sib] to account for non-alternation of exceptional segments. In Table 26, we see lexical items with two exceptional segments (i.e. ones indexed '1'). The winning candidates in this case are those that are fully faithful to their inputs, unaffected by the markedness constraints driving spirantization, since they are non-alternating, exceptional segments.

Table 26. Words containing two non-alternating, exceptional segments (Set 1)

Input	Output	IDENT-IO[cont]$_1$	*V-STOP	*[+cont, -sib]	*STOP	IDENT-IO[cont]
/χ_1p$_1$s/+(3p.past) *'looked for'*	☞a. $\chi_1$ip$_1$es		*	*	*	
	b. k$_1$ip$_1$es	*!	*		**	*
	c. $\chi_1$if$_1$es	*!		**		*
	d. k$_1$if$_1$es	*!*		*	*	**
/χ_1p$_1$s/+(inf.) *'to look for'*	☞a. le$\chi_1$ap$_1$es		*	*	*	
	b. lek$_1$ap$_1$es	*!	**		**	*
	c. le$\chi_1$af$_1$es	*!		**		*
	d. lek$_1$af$_1$es	*!*	*	*	*	**

In Table 27, we see how extending set-indexation to the segmental level can account for hybrid words containing one exceptional segment (belonging to Set 1) and one alternating segment (not indexed for set membership). While IDENT-IO[cont]$_1$ ensures non-alternation of the exceptional segment, the markedness constraints *V-STOP and *[+cont, -sib] determine the alternation of the segment that is not indexed to the highly ranked faithfulness constraint. Crucially, word-level approaches to exceptionality would not be able to handle cases such as those in Table 27 since all segments in the word would be predicted to be either exceptional or alternating.

Table 27. Hybrid words with one un-indexed segment and another from Set 1

Input	Output	IDENT-IO[cont]$_1$	*V-STOP	*[+cont, -sib]	*STOP	IDENT-IO[cont]
/$k_1$br/ + (inf.) *'to bury'*	☞a. li$k_1$bor		*		**	
	b. li$\chi_1$bor	*!		*	*	*
	c. li$\chi_1$vor	*!		**		**
	d. li$k_1$vor		*	*!	*	*
/$k_1$br/ + (3p.past) *'buried'*	☞a. $k_1$avar			*	*	*
	b. $\chi_1$avar	*!		**		**
	c. $\chi_1$abar	*!	*	*	*	*
	d. $k_1$abar		*!			

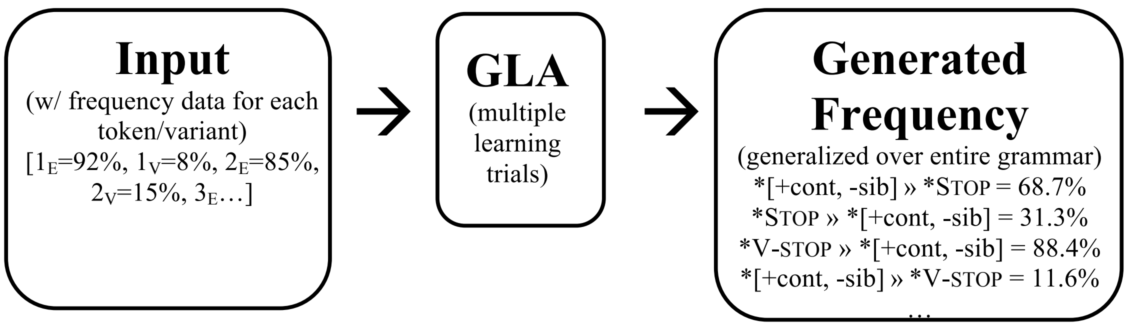
To account for the variation found in the rating task described in Section 2.6, the markedness constraints involved in spirantization will be stochastically ranked relative to each other. Prior to demonstrating the interaction of set-indexation with stochastic ranking, I will provide a summary of Stochastic OT.

2.7.3 Analysis of Variation

2.7.3.1 Stochastic Optimality Theory

Stochastic OT employs probabilistic ranking of constraints to account for variation and gradience (Boersma 1998, Hayes & MacEachern 1998, Zuraw 2000, Boersma & Hayes 2001, Hayes & Londe 2006). Within this approach, each constraint is assigned a ranking value for any given utterance using the Gradual Learning Algorithm (GLA). The model, based on the GLA, predicts that grammar outputs are affected by lexical variant frequency, with the potential to produce variation in the output of the generative system. Figure 6 shows a schema of the way in which the GLA operates over the variant lexical frequencies in the input.

Figure 6. From input frequencies to generated frequency using the GLA



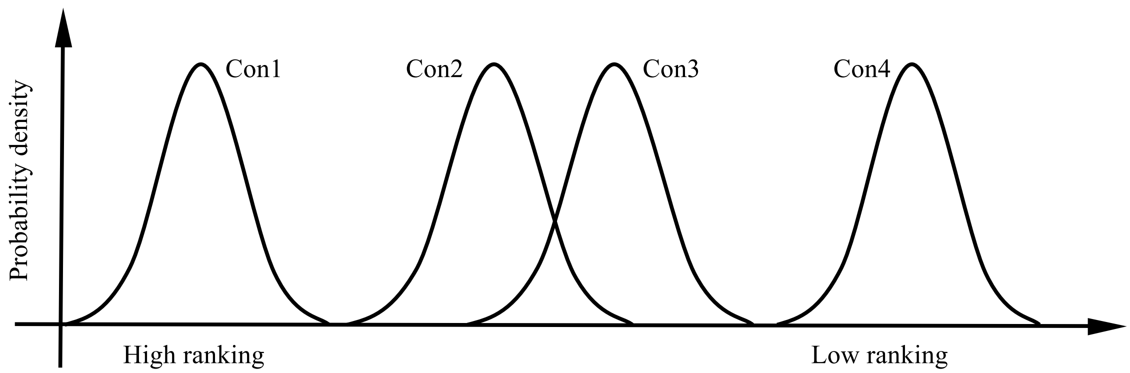
The generated frequencies, though driven by the frequencies in the input (in this case, percentages of acceptability from the pilot study outlined in Section 2.6), are not a mirror copy of them. Rather, the candidates (1E=expected for token 1, 1V=variant for token 1, etc.) are processed through the algorithm a high number of times resulting in a generated frequency number that is then assigned to each of the candidates based on the interaction of the constraints which derive it. Candidates' generated frequencies correspond to a ranking value assigned to each of the constraints, predicting the amount of possible overlap between the distributions of any two active constraints in the evaluation. This is described in more detail in Section 4.3.1

When entering the data from the pilot study, I entered a summary of acceptability ratings (percent of acceptability rating) for each of the variants as the input for the GLA. This means that candidates for all lexical forms were included in the grammar for the calculation of the generated frequency as well as the ranking values.[13]

A schematic for a hypothetical constraint system is seen in Figure 7. This system shows the interaction and probabilistic ranking of four constraints. Because the range (or distribution) of all the constraints is identical according to the GLA, the distance between constraints (as is determined by their ranking values) dictates the degree of overlap between the two constraint. The constraint Con_1 will very likely never be ranked lower than the other three, due to its high ranking value and lack of overlap. Similarly, it is highly unlikely that the constraint Con_4 will ever rank higher than the others due to its low ranking value and lack of overlap. The constraints Con_2 and Con_3, however, share similar ranking values and overlap in their probability densities. This means that the interaction between these two constraints (i.e. whether Con_2 is ranked higher or lower than Con_3) will determine which form of those in variation will occur in the output. Crucially, these two constraints not only account for free variation, or exact equal probability; their ranking will vary depending on the probabilities generated by the GLA using variant lexical frequencies in the input.

[13] Ideally, if we were to have multiple ratings for a given variant from each of the subjects, we would have entered each of the subjects' ratings as the input for a given grammar. Since there were only single iterations of a given variant for each of the subjects, this was not possible.

Figure 7. Hypothetical constraint system (adapted from Zuraw (2000)



In the following section, the stochastic ranking of the markedness constraints involved in the analysis of Modern Hebrew spirantization is similar to the overlap between Con_2 and Con_3 seen in Figure 7.

2.7.3.2 Applying Stochastic OT to Variation in Modern Hebrew Spirantization

To generate the constraint ranking values for Modern Hebrew spirantization, the frequency values reported for each of the variants in the pilot study described in Section 2.6 were entered as one grammar into OTSoft (Hayes et al. 2003). Based on the constraint violations entered for each of the variants, OTSoft generated ranking values for the constraints after testing the grammar through the GLA for 2,000 cycles with a total of 50,000 learning trials.

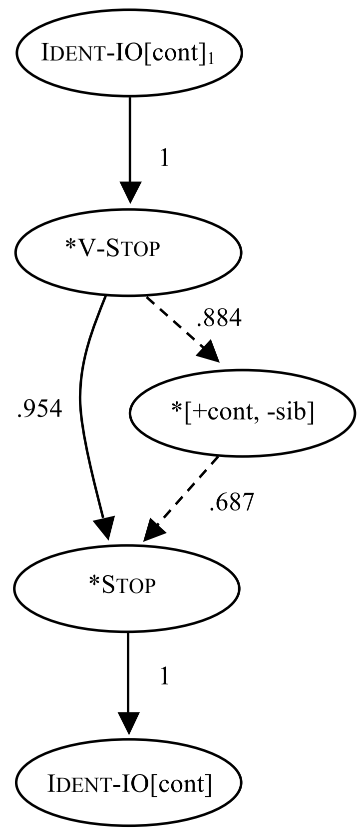
The input frequencies for each candidate were determined by dividing instances in which a variant was deemed acceptable (rated 1 or 2) by the sum of those instances of both forms of a given word. For example, 22 subjects rated the expected form [pizer] as acceptable, while only two subjects rated its variant form [fizer] acceptable. With a total of 24 iterations of acceptable ratings, [pizer] was deemed acceptable 92% of the time whereas [fizer] was deemed acceptable only 8% of the time. After entering the input frequencies for each of the 19 lexemes used in the experiment, OTSoft ran the grammar through the GLA and produced the following ranking values for the constraints used, with an initial ranking value of 100 for each of the constraints.

Table 28. Ranking values found through OTSoft

Constraint	**Ranking Value**
IDENT-IO[cont]$_1$	114.000
*V-STOP	101.470
*[+cont, -sib]	99.692
*STOP	98.308
IDENT-IO[cont]	72.260

Following in Figure 8 is a Hasse diagram illustrating the probability that each constraint used in this analysis will outrank another based on these ranking values. As is seen in Figure 8, the probability that a given constraint will outrank another is notated beside the line connecting the two constraints. A dashed line indicates a stochastic domination relationship in which it is reasonable to expect the opposite ranking. A solid line or arc depicts a categorical or near-categorical domination relationship between the two constraints involved. To avoid clutter, strict domination relationships were assumed through transitivity, although this is not explicitly illustrated.

Figure 8. Hasse diagram of constraint rankings for Modern Hebrew spirantization



The Hasse diagram above shows that the two faithfulness constraints—IDENT-IO[cont]$_1$ and IDENT-IO[cont]—are not in a stochastic domination relationship with any other constraint. It is clear that IDENT-IO[cont]$_1$ must outrank the relevant markedness constraints, whereas IDENT-IO[cont] must be ranked lower than all markedness constraints for spirantization. The domination relationships illustrated here lead to the four constraint rankings necessary to account for alternation, exceptionality and variation in Modern Hebrew spirantization. These rankings appear in (15).

(15) Possible rankings predicted by the GLA listed in order of probability

a. IDENT-IO[cont]$_1$ » *V-STOP » *[+cont,-sib] » *STOP » IDENT-IO[cont]
In alternating segments, stops are prohibited in post-vocalic context but preferred in all other contexts.

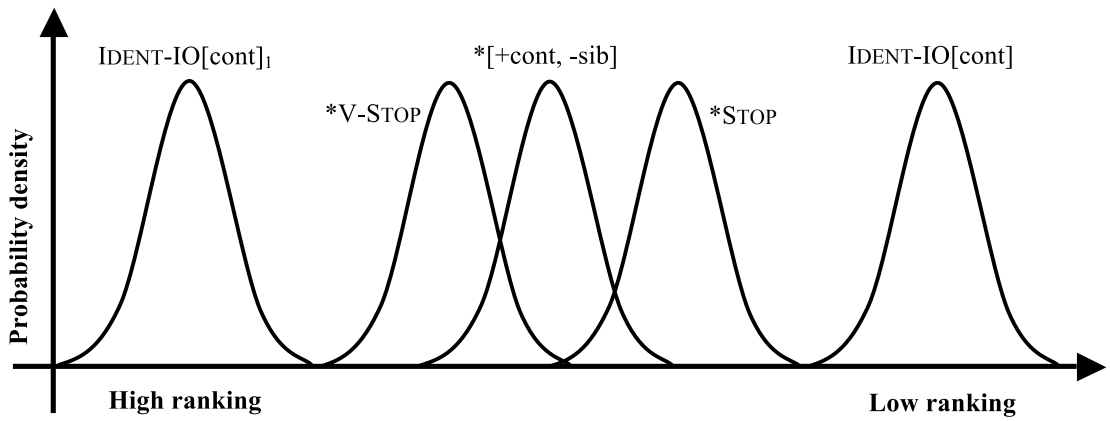
b. IDENT-IO[cont]$_1$ » *V-STOP » *STOP » *[+cont, -sib] » IDENT-IO[cont]
In alternating segments, fricatives are preferred in all contexts.

c. IDENT-IO[cont]$_1$ » *[+cont, -sib] » *V-STOP » *STOP » IDENT-IO[cont]
In alternating segments, stops are preferred in all contexts.

d. IDENT-IO[cont]$_1$ » *STOP » *V-STOP » *[+cont, -sib] » IDENT-IO[cont]
In alternating segments, fricatives are preferred in all contexts.

Given the rankings outlined in Figure 8 and (15), the following diagram shows the possible overlaps in the constraint system used to account for Modern Hebrew spirantization. Note that *STOP has a wide range of overlap with other constraints since, even though its ranking value is the lowest of the markedness constraints, there is still a 4.6% chance that it will be higher ranked than *V-Stop, and a 31% chance that it will be higher ranked than *[+cont, -sib].

Figure 9. Schema for the Modern Hebrew spirantization constraint system



In what follows, I illustrate how different tokens from the pilot study arise from the rankings in (15). When the ranking in (a) occurs, the alternating segments follow the spirantization distribution with fricatives surfacing in post-vocalic context and stops surfacing elsewhere. When the rankings in (b) and (d) occur, alternating segments surface only as fricatives, and when the rankings in (c) occur, only stops surface for these segments. Examples for the three most frequent rankings (rankings a, b, and c) are shown.

Combining Stochastic OT with the lexically-indexed faithfulness constraints, we can account for variation in non-hybrid words with a stochastic ranking of the context-free markedness constraints relative to each other. Illustrated in Table 29 are the two most plausible candidates for the third person singular form of the root /pzr/. In the pilot study, the expected form [pizer] was rated acceptable 92% of the time, whereas the variant form [fizer] was rated acceptable 8% of the time. Using the GLA, the generated frequency for the two forms was changed to 68.4% and 31.6%, respectively.

Table 29. [pizer] (expected, *68.4%*) ~ [fizer] (variant, *31.6%*)[14]

*A. [pizer] = *[+cont, -sib] » *STOP (occurs 68.7% in grammar):*

/pzr/+3p.pst.m 'he spread'	IDENT-IO [cont]$_1$	*V-STOP	*[+cont, -sib]	*STOP	IDENT-IO[cont]
☞a. pizer				*	
b. fizer			*!		*

*B. [fizer] = *STOP » *[+cont, -sib] (occurs 31.3% in grammar) :*

/pzr/+3p.pst.m 'he spread'	IDENT-IO[cont]$_1$	*V-STOP	*STOP	*[+cont, -sib]	IDENT-IO[cont]
a. pizer			*!		
☞b. fizer				*	*

Looking at a root with an alternating medial segment and no exceptional segments, Table 30 shows the need for the possible ranking of the constraint against non-sibilant fricatives over the contextual markedness constraint driving spirantization. In Table 30, we see the two forms [ʃavar] (expected) and [ʃabar] (variant) which generated a frequency of 76% and 24%, respectively, using the GLA. The variant form drives the ranking of *[+cont, -sib] over *V-STOP with a stop occurring in post-vocalic context.

Table 30. [ʃavar] (expected, *76%*) ~ [ʃabar] (variant, *24%*)

*A. [ʃavar] = *V-STOP » *[+cont, -sib] (occurs 88.4% in grammar):*

/ʃbr/+3p.pst.m 'he spread'	IDENT-IO[cont]$_1$	*V-STOP	*[+cont, -sib]	*STOP	IDENT-IO[cont]
☞a. ʃavar			*		*
b. ʃabar		*!		*	

[14] Dotted lines between constraints represent stochastic rankings.

*B. [ʃabar] = *[+cont, -sib] » *V-STOP (occurs 11.6% in grammar):*

/ʃbr/+3p.pst.m *'he spread'*	**IDENT-IO[cont]₁**	***[+cont, -sib]**	***V-STOP**	***STOP**	**IDENT-IO[cont]**
a. ʃavar		*!			*
☞b. ʃabar			*	*	

Variation in hybrid words is also possible using this combined model through the ranking of IDENT-IO[cont] above the spirantization-driving markedness constraints. This constraint has the highest ranking value in the grammar's hierarchy (a value of 114) and categorically dominates the relevant markedness constraints. In Table 31 and Table 32, we see the hybrid cases and the ability of the combined model to account for these as well. The two tableaux in Table 31 demonstrate the argument for stochastic ranking of the two context-free markedness constraints, with the variant form [likvor] requiring *STOP to dominate *[+cont, -sib]. The alternating segment is root-medial and, in the infinitive form, occurs in post-consonantal context. The contextual markedness constraint against post-vocalic stops does not play a role in determining the winning candidate for this input since there is an exceptional stop occurring in post-vocalic context.

Table 31. [likbor] (expected, *68.4%*) ~ [likvor] (variant, *31.6%*)

*A. [likbor] = *[+cont, -sib] » *STOP (occurs 68.7% in grammar):*

/$k_1$br/ + inf. *'to bury'*	**IDENT-IO[cont]₁**	***V-STOP**	***[+cont, -sib]**	***STOP**	**IDENT-IO[cont]**
a. lik₁vor		*	*!	*	*
☞b. lik₁bor		*		**	
c. liχ₁vor	*!		**		**
d. liχ₁bor	*!		*	*	*

*B. [likvor] = *STOP » *[+cont, -sib] (occurs 31.3% in grammar):*

/k$_A$br/ + inf. *'to bury'*	**IDENT-IO[cont]$_1$**	***V-STOP**	***STOP**	***[+cont, -sib]**	**IDENT-IO[cont]**
☞a. lik$_1$vor		*	*	*	*
b. lik$_1$bor		*	**!		
c. li$\chi_1$vor	*!			**	**
d. li$\chi_1$bor	*!		*	*	*

In Table 32, we see a hybrid form with an exceptional segment in root-medial position and an alternating segment in root-initial position. The variation occurs in the root-initial segment in post-vocalic context. Here we see that the ranking of *[+cont, -sib] higher or lower than *V-STOP determines whether variation occurs.

Table 32. [levakeʃ] (expected, 76%) ~ [lebakeʃ] (variant, 24%)

*A. [levakeʃ] = *V-STOP » *[+cont, -sib] (occurs 88.4% in grammar)*

/bk$_1$ʃ/ + inf. *'to ask for'*	**IDENT-IO[cont]$_1$**	***V-STOP**	***STOP**	***[+cont, -sib]**	**IDENT-IO[cont]**
☞a. levak$_1$eʃ		*	*	*	*
b. lebak$_1$eʃ		**!	**		
c. levaχ_1eʃ	*!			**	**
d. lebaχ_1eʃ	*!		*	*	*

*B. [lebakeʃ] = *[+cont, -sib] » *V-STOP (occurs 11.6% in grammar)*

/bk$_1$ʃ/ + inf. *'to ask for'*	**IDENT-IO[cont]$_1$**	***[+cont, -sib]**	***V-STOP**	***STOP**	**IDENT-IO[cont]**
a. lvak$_1$eʃ		*!	*	*	*
☞b. lebak$_1$eʃ			**	**	
c. levaχ_1eʃ	*!	**			**
d. lebaχ_1eʃ	*!	*		*	*

Running all tokens and their attested forms through the GLA, nearly all generated frequencies matched the input frequencies from the experiment results in their preference patterns.[15] The forms in which there was a mismatch in preference patters between the input frequencies and the generated frequencies are forms in which there was a post-consonantal voiceless labial ([jidpok], [jidfok] and [jaχpor], [jaχfor]). Recall that, in the experiment, these behaved differently from other segments and contexts in that there was a preference for the variant rather than the expected form. In the follow-up study described in Chapter 3, the presence of more tokens in post-consonantal condition will provide more information about the nature of the variation seen here, and will eliminate the possibility of lexical effects of the two roots used in the pilot study.

2.8 Chapter Summary

In this chapter, I introduced Modern Hebrew spirantization as a phenomenon of alternation for which there two sources of non-conformity, exceptionality and variation. I provided a diachronic account of exceptionality, demonstrating that present-day exceptions in Hebrew are due to historical sound mergers. Based on the existence of hybrid words, which contain both alternating and exceptional segments, I argued that exceptionality must be encoded at the segmental level, and I proposed extending Pater's (2000) lexical indexation approach to the segmental-level to account for it.

In this chapter I also provided details of a pilot study designed to test the acceptability of variation in sounds normally conforming to the spirantization distribution. The results showed that although variation is acceptable, speakers prefer the form expected by the spirantization distribution over the variant form in most cases. To

[15] To compare matches in preference patterns, I checked to see that each of the forms' input frequency and generated frequency were on the same side of the midpoint on the 0.00-1.00 scale.

account for this variation, I proposed using Stochastic OT to allow for variable ranking of constraints. The results of the pilot study and the preliminary analysis described in this chapter shape the goals of the experimental rating task I discuss in Chapter 3.

3 Perception Study

In the previous chapters, I introduced exceptionality and variation as two patterns of non-conformity, with exceptionality showing absolute non-conformity and variation demonstrating partial non-conformity. I also introduced spirantization in Modern Hebrew as a multi-faceted phenomenon with both alternating segments and exceptional, non-alternating segments and described a pilot perception study testing the acceptability of variation in the alternating segments.

The present chapter describes an acceptability rating task for Modern Hebrew designed as a follow up to the pilot study in Section 2.6. The task elicits data not previously available concerning speakers' intuitions about variation in both alternating and exceptional segments with respect to spirantization. The goals of this study are to examine the acceptability of variation in alternating consonant pairs, to determine whether variation in exceptional segments is acceptable, and to investigate the acceptability of variation in a single word containing two target segments. Studying the acceptability of variation—and particularly variation in exceptional segments—will help us to better understand patterns of non-conformity in language. It will also provide a fuller description of non-conformity in Modern Hebrew spirantization on which to test theoretical approaches and build an analysis in Chapter 4.

3.1 Goals and Hypotheses

3.1.1 Examining the Acceptability of Variation in Alternating Pairs

Based on the results of the pilot experiment and subsequent Stochastic OT analysis, I predict that some variation in segments normally conforming to the spirantization distribution will be deemed acceptable. Recall that, according to the spirantization distribution, fricatives are expected in post-vocalic contexts and stops are expected in word-initial and post-consonantal contexts. The *variant* forms of these segments, then, are stops in post-vocalic contexts and fricatives in word-initial and post-consonantal contexts. This is illustrated for word-initial and post-vocalic position in Table 33.

Table 33. Expected and variant forms in the spirantization distribution

Pair	**Root**	**3^{rd} Person Sg. Past**		**Infinitive**		**Gloss**
		Expected (word-initial stop)	**Variant (word-initial fricative)**	**Expected (post-vocalic fricative)**	**Variant (post-vocalic stop)**	
/p/ → [f]	/**p**rs/	[**p**aras]	[**f**aras]	[li**f**ros]	[li**p**ros]	‘to spread’
/b/ → [v]	/**b**nh/	[**b**ana]	[**v**ana]	[li**v**not]	[li**b**not]	‘to build’
/k/ → [χ]	/**k**tb/	[**k**atav]	[**χ**atav]	[li**χ**tov]	[li**k**tov]	‘to write’

Based on the results of the pilot study, I further hypothesize that such variant forms will be deemed less acceptable than the corresponding *expected* forms (i.e. those conforming to the spirantization distribution). Such a result could be interpreted as evidence against Adam’s (2002) claim that the variant and expected segments are in free variation.

The pilot results showing that Modern Hebrew spirantization does not have free variation are summarized in Table 34. The expected forms of all three consonant pairs were judged significantly more acceptable than their variant counterparts in all but one environment. Each cell contains the average 1-to-4 rating of the tokens in a particular condition, with a rating of 1 being equivalent to 'very likely' and 4 equivalent to 'very unlikely'. The bolded scores within each cell represent the more likely form for that condition.

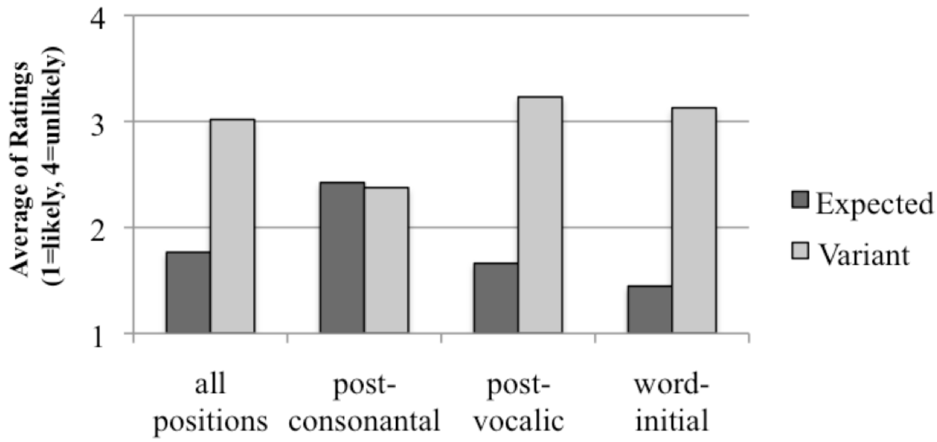
Table 34. Preferences within pairs and environments (from pilot study)

Pair	Word-initial		Post-vocalic		Post-consonantal	
b/v	**Expected (1.15)**	Variant (3.46)	**Expected (1.41)**	Variant (2.75)	**Expected (1.88)**	Variant (2.88)
p/f	**Expected (1.17)**	Variant (3.69)	**Expected (1.66)**	Variant (3.40)	Expected (2.96)	**Variant (1.87)**
k/χ	**Expected (1.86)**	Variant (2.23)	**Expected (1.91)**	Variant (3.32)	No data	No data

The results of the pilot study revealed a significant interaction between *allophone* (whether a token was the variant or expected form) and *phonetic context* (i.e. word-initial, post-vocalic, post-consonantal) for alternating segments. This interaction seems to have been driven by the ratings of the post-consonantal tokens, as is seen in Figure 10. Unlike those in other contexts, these variant forms were judged no more or less acceptable than their expected counterparts, approaching free variation.[16]

[16] Unlike the other positions, the acceptability ratings of expected versus variant tokens in this position were not significantly different from each other. Analysis showed that this was driven by the acceptability of the variant form of [f] in this position.

Figure 10. Average ratings by position



Adam (2002) describes variation as acceptable in all three alternating consonant pairs in both word-initial and post-consonantal contexts. However, according to her description, in post-vocalic context only the velar exhibits variation. Recall from the pilot study in Section 2.6 that variation in post-consonantal labials was deemed acceptable as well. In fact, in the case of the voiceless labial pair – p/f – participants preferred the variant form. Based on these findings, I expect phonetic context to play a role in the acceptability of variation. However, due to the conflicting predictions of the previous literature and the pilot study, I cannot predict the nature or breadth of this variation. My informal prediction is that results in this study will be similar to those of the pilot study.

3.1.2 Determining Whether Variation is Acceptable in Exceptional Segments

In the pilot study, the acceptability of variation was only tested in segments that normally participate in the spirantization distribution, including but not limited to those discussed in Adam (2002). In the study described in this chapter, stimuli with variant forms of exceptional (non-alternating) segments were included as well. Given the lack of data on variation in exceptional segments, and preliminary testing with native speakers in which variation was deemed unacceptable for exceptional segments, I hypothesize that, if variation in exceptional segments is acceptable, it will be judged as less acceptable than variation in alternating segments. This hypothesis is based on the assumption that, unlike alternating segments, exceptional segments are members of a set with a corresponding faithfulness constraint. In the analysis of Modern Hebrew spirantization in Section 2.7.2, the set-indexed constraint is in a near-strict domination relationship with the markedness constraints driving the spirantization.

3.1.3 Investigating Acceptability of Variation in Words with Multiple Segments

This study looked at (i) roots containing one regularly alternating segment, (ii) roots containing one exceptional segment, (iii) roots containing two alternating segments, and (iv) roots containing one alternating segment and one exceptional segment, which I will refer to as hybrid roots. Thus, this study builds on the pilot study by also including variation in exceptional segments and in words containing two target segments. Based on the assumptions (stated in the previous sections) regarding the scope of variation in words containing only one target segment (either alternating or exceptional), acceptability of variation of either segment in a hybrid word is predicted to be similar to that segment's acceptability when it is the only target segment in a given word. This prediction presupposes that the other segment in the hybrid word is in its expected form (i.e. not in the variant form). This is based on the assumption that a hybrid with an alternating segment in its expected form is like any word containing an exceptional segment in it. This means that, once again, variation in alternating segments is expected to be more acceptable than variation in exceptional segments. This follows from the OT analysis in Section 2.7, in which all exceptional segments are indexed to a single exceptional set. The prediction is that the acceptability of variation in exceptional segments will not differ based on the presence of the expected form of the alternating segments in the same word, given that the second target segment in the same word is presented in its expected form. Additionally, it is predicted that hybrid words containing the variant forms of both target segments will be less acceptable than hybrids containing only one variant form and one expected form.

Recall from Table 32, repeated below as Table 35, that the strict domination of the markedness constraints for spirantization by IDENT-IO[cont]$_1$ ensures that exceptional segments in hybrid words will remain fixed, while allowing for variation in the alternating segments with stochastic rankings of the markedness constraints. This near-strict domination by IDENT-IO[cont]$_1$, predicting a lack of variation in exceptional segments, was assumed in this analysis based on the pilot study, in which variation was not tested in exceptional segments. In the analysis provided in Chapter 4, pending results of the present study, the ranking of IDENT-IO[cont]$_1$ will be determined based on participants' ratings of words containing variants of exceptional segments, and could very well be stochastically ranked with respect to one or more of the markedness constraints if some variation is found acceptable.

Table 35. [levakeʃ] (expected, 76%) ~ [lebakeʃ] (variant, 24%)

*A. [levakeʃ] = *V-STOP » *[+cont, -sib] (occurs 88.4% in grammar)*

/bk₁ʃ/ + inf. *'to ask for'*	**IDENT-IO[cont]₁**	***V-STOP**	***STOP**	***[+cont, -sib]**	**IDENT-IO[cont]**
☞a. levak₁eʃ		*	*	*	*
b. lebak₁eʃ		**!	**		
c. levaχ₁eʃ	*!			**	*
d. lebaχ₁eʃ	*!		*	*	

*B. [lebakeʃ] = *[+cont, -sib] » *V-STOP (occurs 11.6% in grammar)*

/bk₁ʃ/ + inf. *'to ask for'*	**IDENT-IO[cont]₁**	***[+cont, -sib]**	***V-STOP**	***STOP**	**IDENT-IO[cont]**
a. levak₁eʃ		*!	*	*	*
☞b. lebak₁eʃ			**	**	
c. levaχ₁eʃ	*!	**			*
d. lebaχ₁eʃ	*!	*		*	

In addition to hybrid words, words containing two alternating segments were also included in the study. The constraint rankings used in the OT analysis of tokens in the pilot study predict only three patterns of variation in roots containing two alternating segments in C_1 and C_2 positions. Namely, it is predicted that variant segments may occur in either the first or second consonant or neither, but not simultaneously in both. This prediction is tied to a property of Modern Hebrew words whereby alternating C_1 and C_2 occur in distinct phonetic contexts. Triconsonantal roots containing two alternating segments in C_1 and C_2 positions pattern such that one occurs in post-vocalic context and the other occurs in non-post-vocalic contexts. The ranking of markedness constraints is such that it does not allow for both a variant stop and a variant fricative to occur in the output of a single form. This predicts that words containing two alternating segments in their variant forms will be less acceptable than forms containing only one variant form and one expected form. A summary of predicted patterns of variation in words containing two alternating segments is given in Table 36.

Table 36. Predicted variation in words containing two alternating segments

	No Variation	**1^{st} Varies**	**2^{nd} Varies**	**Both Vary**
PV* – NPV*	yes	yes	yes	no
NPV – PV	yes	yes	yes	no

*PV = post-vocalic context, **NPV = non-post-vocalic context

In summary, in this study, I examine the acceptability of variation in alternating segments and the effect of segment position on acceptability. Additionally, I look at the degree to which variation is acceptable in exceptional forms, and test whether the analytic model proposed in 2.7 successfully accounts for variation in words containing two alternating segments. The hypotheses are outlined in Table 37.

Table 37. Summary of hypotheses

1	***Alternating Segments***
	1a. Variation is acceptable
	1b. Not free variation: variation is biased to expected form
	1c. Positional effects
2	***Exceptional Segments***
	2a. If any variation, then less than variation in alternating segments
	2b. Positional effects
3	***Words Containing two Segments***
	3a. Words with two variant segments will be less acceptable than words containing only one variant (because they occur in distinct contexts)
	3b. Variants for alternating segments in hybrids will be as acceptable as in 1a
	3c. Variants for exceptional segments in hybrids will be as acceptable as 2a

3.2 Methods

3.2.1 Stimuli

In the web-based rating task described here, subjects were asked to rate the naturalness of the pronunciation of verbs containing segments of the type under study. Stimuli included verbs whose roots contain one target segment (either alternating or exceptional), 'hybrid' roots (containing one alternating segment and one exceptional segment) and roots containing two alternating segments. Roots containing two alternating segments were used to test the third hypothesis, while 'hybrid' roots were used for post hoc tests to see whether there is a change in acceptability ratings between roots containing a single exceptional segment (with no alternating segment present) and those containing both types of segments in a single root.

I selected tri-consonantal roots, including but not limited to those discussed in Adam (2002). For the *alternating segments*, roots with /b/, /p/, or /k/ in either initial or medial position were selected. Eight roots were used for each segment, four with the segment in root-initial position and four with it in root-medial position, for a total of 24 roots. Two forms of each root were used, placing the target segment in word-initial and post-vocalic context (for root-initial segments) or post-vocalic and post-consonantal context (for root-medial segments). This is illustrated in Table 38.

Table 38. Placement of target segments within roots in stimuli

Target Segment Context		**3rd Person Singular Past**		**Infinitive**	
Root-initial	/**b**tl/	word-initial	[**b**itel]	post-vocalic	[le**v**atel]
Root-medial	/s**b**l/	post-vocalic	[sa**v**al]	post-consonantal	[lis**b**ol]

For the *exceptional segments*, due to the lack of high-frequency tokens in some cases, I only selected a total of four roots (two with a root-initial exceptional segment and two with a root-medial exceptional segment) for each of the four exceptional segments.[17] In the case of exceptional /f/, only one root was used for the post-consonantal position. Unlike tri-consonantal roots, the /f/ in conjugations for the four-consonant root (/tlfn/ – ‘to telephone’) always occurs in post-consonantal context. For this reason, I used two conjugations of this root to fulfill the requirement for two words with post-consonantal exceptional /f/. This means that, unlike other conditions, all tokens containing exceptional /f/ in post-consonantal context were from this root, /tlfn/.[18]

In addition to roots with one target segment (either alternating or exceptional), I also tested four hybrid roots and two roots containing two alternating segments, using the two forms of the verb illustrated in Table 38. Each of the target words was recorded in both the expected form (alternating as predicted by the spirantization distribution for the alternating segments, and the non-alternating form for the exceptional segments) and variant form (behaving opposite to the spirantization distribution for the alternating segments, and the stop or fricative counterpart for the exceptional form) yielding a total of 204 stimuli. Some sample target words appear in Table 39.

[17] Exceptional /p/ and /b/, both derived from geminates in older forms of Hebrew, were excluded as they only occur in root-medial position, and only in certain templates.
[18] /tlfn/ was also the only four-consonant root used in the experiment.

Table 39. Sample target words

Root	(E)wi	(V)wi	(E)pv	(V)pv	(E)pc	(V)pc	Gloss
/btl /	bitel	vitel	mevatel	mebatel			Cancel
/bdk/	badak	vadak	livdok	libdok			Check
/sbl/			saval	sabal	lisbol	lisvol	Suffer
/gbi/			gava	gaba	ligbot	ligvot	Collect ($)
/ʃbr/			ʃavar	ʃabar	liʃbor	liʃvor	Break
/lbʃ/			lavaʃ	labaʃ	lilboʃ	lilvoʃ	Wear

(Key: E=expected, V=variant, wi=word-initial, pv=post-vocalic, pc=post-consonantal)

Alternating and exceptional forms were controlled for frequency by using neither the most frequent nor least frequent 5% of lexemes in a Hebrew verb frequency corpus provided by Shmuel Bolozky. Since the items in the corpus were drawn from text (largely periodicals), some verbs – particularly borrowings – were not present. In these cases, the Word-Frequency Database for Printed Hebrew (Frost & Plaut 2001) was used. The number of stimuli in each condition is shown in Table 40 and Table 41. The columns in Table 41 refer to the form of each of the target segments, for example 1Exp2Var means that the first consonant is in its expected form and the second one is in its variant form. A complete list of the target words used in the experiment appears in Appendix A.

Table 40. Summary of stimuli number within condition: tokens with one segment

	Segment	**Word-initial**		**Post-vocalic**		**Post-consonantal**		**Total Tokens**
		Exp	Var	Exp	Var	Exp	Var	
Alternating	/p/ (p/f)	4	4	8	8	4	4	32
	/b/ (b/v)	4	4	8	8	4	4	32
	/k/ (k/χ)	4	4	8	8	4	4	32
Exceptional	/k/ <*q	2	2	4	4	2	2	16
	/v/ <*w	2	2	4	4	2	2	16
	/χ/ <*ħ	2	2	4	4	2	2	16
	/f/	2	2	2	2	2	2	12
	Total	**20**	**20**	**38**	**38**	**20**	**20**	**156**

Table 41. Summary of stimuli number within condition: tokens with two segments

	C_1VC_2V				VC_1C_2V				Total
	1Exp2Exp	1Exp2Var	1Var2Exp	1Var2Var	1Exp2Exp	1Exp2Var	1Var2Exp	1Var2Var	
2 Alternating	2	2	2	2	2	2	2	2	16
Hybrid	6	6	6	6	2	2	2	2	32
									48

To make the sentences as natural-sounding as possible, the 204 target expected/variant word pairs were embedded in carrier sentences. Following each of the verbs was a context-specific four-syllable ending of the sentence (i.e. if the verb was 'to wash', the ending could be 'in the bathroom'). Additionally, depending on the number of syllables in the target word, three different sentence beginnings were used to ensure that all sentences contained the same number of syllables (namely, 12). Some sample carrier sentences appear in (16).

(16) Sample carrier sentences for target words

Past

[amru li ʃedaniel (target word) le/be/me/et ________]
told to me that Daniel (target word) to/in/from/the ________
"I've been told that Daniel (target word) to/in/from/the ________"
e.g. "I've been told that Daniel *built* the *hut*"

Infinitive

[amru li ʃedan holeχ (target word) le/be/me/et ________]
told to me that Dan is going (target word) to/in/from ________
"I've been told that Dan will (target word) to/in/from ________"
e.g. "I've been told that Dan will *build* the *hut*"

Present

[amru li ʃedani (target word) le/be/me/et ________]
told to me that Danny (target word) to/in/from ________
"I've been told that Danny (target word) to/in/from ________"
e.g. "I've been told that Danny is *building* the *hut*"

The sentences were recorded at a normal speaking rate by a 33-year old male native Hebrew speaker in the UCLA Phonetics Laboratory using an Equitex IIB microphone. Recordings were made directly into a computer using Audacity at a sampling rate of 44kHz. The decision to use the voice of a male speaker rather than that of a female speaker was made on the assumption that, while females are more likely to drive language change, males are more likely to use nonstandard forms (Labov 1990). The speaker's age was such that his voice would likely sound similar to that of the study participants and their peers.

The duration of each sentence was measured to ensure that token duration is controlled across types. Sentences shorter than 1.5 seconds or longer than 1.75 seconds were re-recorded. In order to minimize the effects of participant fatigue, the list was divided in half in an effort to keep each subject's participation under 30 minutes. Each list was randomized and contained an equal number of tokens from each condition. Since there was only one root used for exceptional /f/ in post-consonantal position, the four tokens for this root appeared on both lists, resulting in 104 tokens on each list. All tokens of a given root were presented in the same list, so as to allow comparison of participants' ratings of different tokens within each root. To neutralize any effect of list order, a reversed version of each list was also used, resulting in a total of four lists, only one of which was rated by any participant.

3.2.2 Participants

Seventy-four native speakers of Modern Hebrew residing in Israel participated in the rating task. Only participants who indicated (on a demographic survey completed afterward) that Hebrew was both their first and home language were included in the analysis.[19] There were 34 male participants and 40 females, ranging in age from 19 to 40.

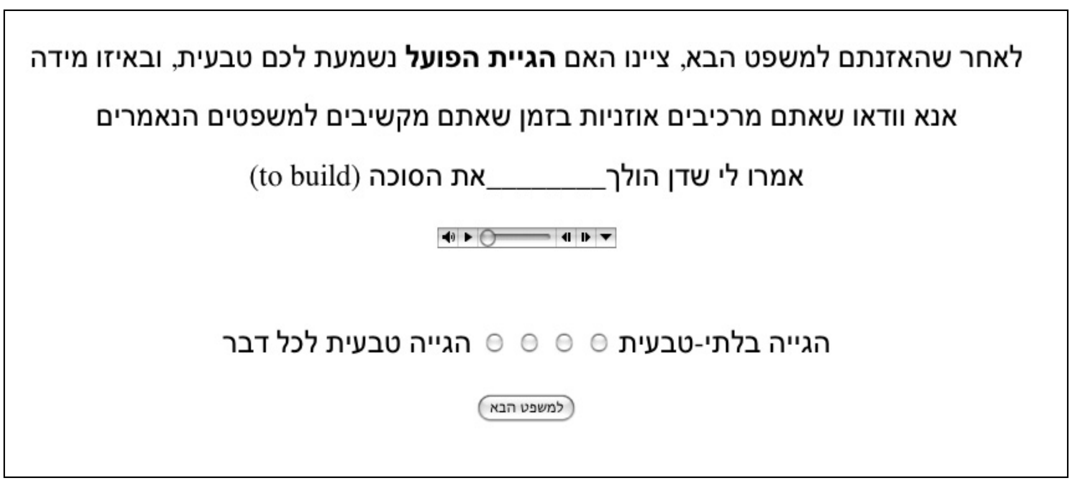
3.2.3 Procedure

The webpage to which participants were directed instructed them to select one of four boxes. Each box was a hyperlink to one of the four lists described in Section 3.2.1. The entire experiment was conducted online using a .php script and nearly all experiment-related materials were in Hebrew.

[19] Of the 88 participants recruited, 14 had marked a language other than Hebrew as their first or home language. Those participants' responses were not analyzed.

After clicking one of the four boxes, participants were instructed (in writing) to listen carefully to each of the sentences using headphones, and to pay special attention to the target verb. Participants were then instructed to rate the target verbs in the sentences as to their naturalness. A ‘natural’ pronunciation of the target verb was described as one that could possibly be uttered by their peers. An unnatural pronunciation was described as one that a native speaker would never utter. Participants had to select one of four radio buttons on the screen with ‘very natural pronunciation’ on the left side of the button set and ‘unnatural pronunciation’ on the right side of the button set, as shown in the screenshot in Figure 11. To disambiguate the target verb (in case some of the variant pronunciations were so unnatural as to render them unrecognizable) the frame sentence appeared just above the media player controls, with a blank in the place of the target root and the English gloss of the infinitive of the target verb following it.[20]

Figure 11. Screen shot of the experiment window



[20] Assuming that all post-secondary-aged participants are proficient in English.

Due to programming limitations, participants were able to listen to each sentence an unlimited number of times before selecting a response and change their response until they moved on to the next sentence. After doing the rating task, participants completed a demographic survey asking for their age, gender, first and home languages, and level of education. This information was used to ensure that all participants met the enrollment criteria for the study.

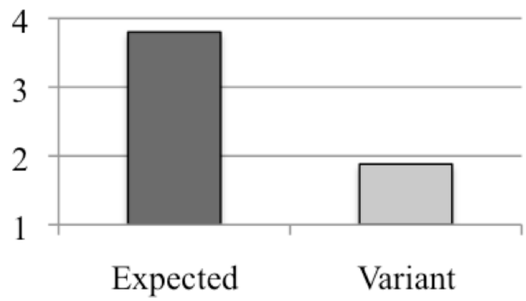
3.3 Results

Participants' responses corresponding to the four radio buttons were recorded on a four-point scale with 'very natural pronunciation' having a score of four and 'unnatural' having a score of one.[21] In the statistical analysis that follows, I use z-scores to control for individual variation in use of the four-point scale.[22] However, the graphs will be based on raw scores (1-4) for ease of visualization.

An analysis of all tokens containing one target segment (either alternating or exceptional) across subjects revealed a preference for the expected form across all positions. A two (allophone: expected vs. variant) by two (type: alternating vs. exceptional) repeated-measures ANOVA revealed a significant main effect of allophone ($F(1, 73) = 886.521$, $p < .001$), showing that, as hypothesized, tokens with the target segment in the expected form were rated more natural than tokens with the target segment in the variant form. Figure 12 shows the average ratings of all words containing one alternating or exceptional segment.

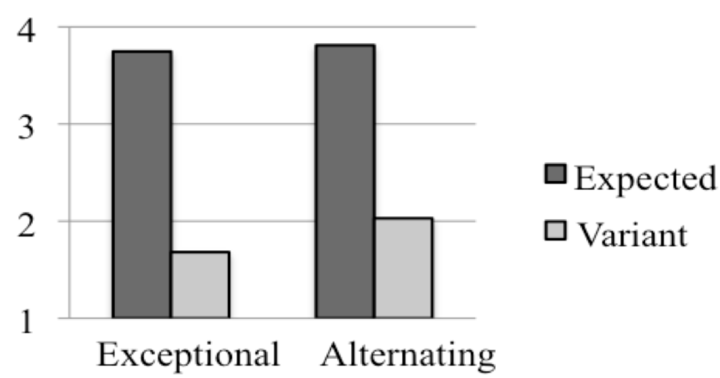
[21] The scale used for scoring the ratings in the pilot study was the opposite.
[22] The use of z-scores also conveniently helped take care of order effects within lists (where the 'forward' list began with 4 expected forms and the 'reverse' list began with 3 variant forms).

Figure 12. Expected vs. variant forms across all tokens



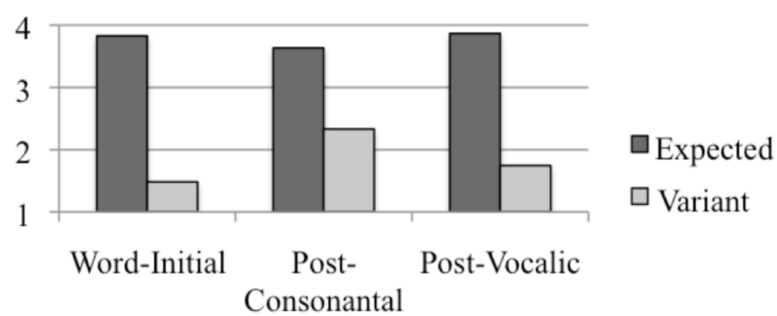
There was also a significant main effect of type ($F(1, 73) = 80.073$, $p < .001$) and a significant interaction between type and allophone ($F(1, 73) = 18.707$, $p < .001$), such that, as hypothesized, variation in exceptional segments was rated less natural than variation in alternating segments. This is seen in Figure 13.

Figure 13. Alternating vs. exceptional segments



The results of a three (position: word-initial vs. post-consonantal vs. post-vocalic) by two (allophone: expected vs. variant) repeated-measures ANOVA also showed a significant main effect of position ($F(2, 72) = 69.369$, $p < .001$) and a significant interaction between position and allophone ($F(2, 72) = 155.768$, $p < .001$). Among tokens containing one alternating segment or one exceptional segment, there was a preference for the expected form in all positions. However, variation was significantly more acceptable in post-consonantal context than in word-initial or post-vocalical contexts. This is illustrated in Figure 14. Different aspects of the post-consonantal position will be further discussed in Section 3.3.2 for alternating segments and in Section 3.3.3 for exceptional segments.

Figure 14. Expected vs. variant forms across positions



3.3.1 Baseline for Acceptability of Variation

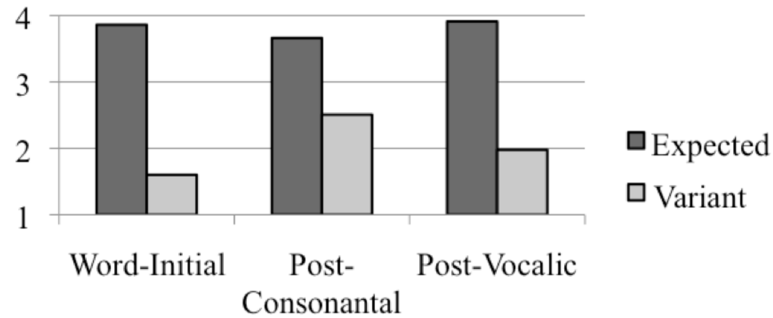
To determine whether variation was acceptable in each of the relevant categories (i.e. words containing one alternating segment, one exceptional segment, or two target segments), I ran paired *t*-tests comparing participants' acceptability judgments of the variant forms within each category with the lowest score on the rating scale (namely, 1). A significantly higher (than 1) rate of acceptability of the variant forms in a given category is interpreted as acceptability of variation in the category in question.

3.3.2 Alternating Segments

Here we will look specifically at the alternating segments, in order to assess the hypothesis presented in Section 3.1.1. Recall that *hypothesis 1a* in Table 37 predicts that variation is acceptable in alternating segments. A paired t-test comparing the acceptability of words containing the variant form of an alternating segment with the baseline revealed that variation in alternating segments is acceptable ($t(73) = 16.844$, $p < .001$). To test whether this variation was in free distribution (*hypothesis 1b*), a paired t-test of participants' average scores for words containing expected and variant forms of alternating segments was performed, revealing a significant difference ($t(73) = 29.848$, $p < .001$). I interpret this difference as a display of lack of free variation, with a clear preference for expected forms.

To test for position effects in alternating segments (*hypothesis 1c*), I ran a three (position: word-initial vs. post-consonantal vs. post-vocalic) by two (allophone: expected vs. variant) repeated-measures ANOVA. The results revealed significant main effects of position ($F(2, 72) = 36.963$, $p < .001$) and allophone ($F(1, 73) = 890.882$, $p < .001$) and a significant interaction between position and allophone ($F(2, 72) = 89.036$, $p < .001$). A closer look at the distribution of acceptability of expected and variant forms revealed that words containing the target segment in post-consonantal position were driving the main effect of position and the interaction of position and allophone, with a higher rate of acceptability of the variant in this position than in others.

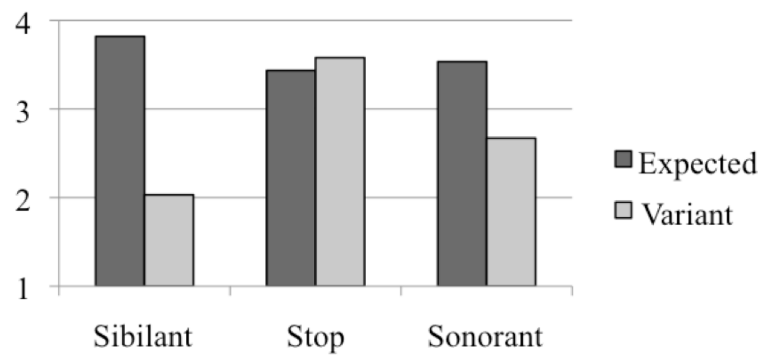
Figure 15. Variation in alternating segments



Paired *t*-tests for variants in post-consonantal vs. word-initial contexts and post-consonantal vs. post-vocalic contexts confirm that the high rate of acceptability of variants in post-consonantal context drives the main effect of position ($t(73) = 12.369$, $p < .001$, and $t(73) = 7.717$, $p < .001$, respectively) by showing that post-consonantal segments behave differently than both word-initial and post-vocalic ones.

A closer look at the post-consonantal position reveals a main effect of the segment preceding the alternating segment within a given target word. Tokens were coded for whether the consonant in this case was a stop, a sibilant, or a sonorant. The results revealed a significant main effect of consonant type ($F(1, 36) = 32.869$, $p < .001$), and a significant interaction of consonant type and allophone ($F(1, 36) = 38.346$, $p < .001$) driven by the higher rating of acceptability of the variant form (a fricative) when following a stop. This is seen in Figure 16.

Figure 16. Variation within postconsonantal position (alternating segments)

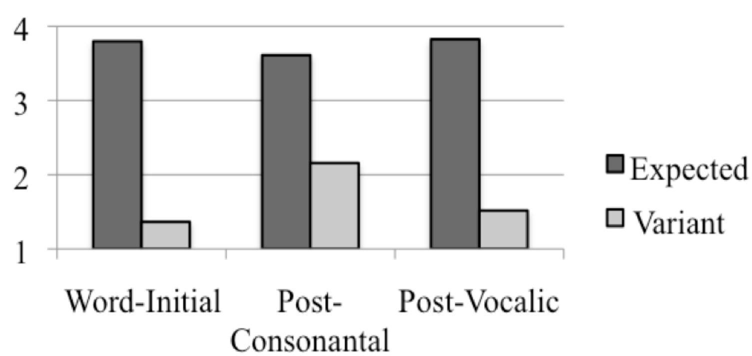


3.3.3 Exceptional Segments

Having considered how well the findings for alternating segments support *hypotheses 1a*, *1b*, and *1c*, we turn to exceptional segments to see how their behavior fit with *hypotheses 2a* and *2b*. In light of the ANOVA results which show a significant main effect of type (whether a segment is alternating or exceptional) and, therefore, suggest that variation is more acceptable in alternating segments than in exceptional ones, I ran further tests to examine the nature of this difference. Recall that *hypothesis 2a* predicts that there should be little to no acceptability of variation in exceptional segments. Mainly, I wanted to exclude the possibility that acceptability of variation of exceptional cases could be due to participant errors. A paired *t*-test comparing participants' ratings of words containing the variant form of an exceptional segment with the baseline revealed a significant difference ($t(73) = 13.614$, $p < .001$). I interpret this as meaning that variation in exceptional segments is indeed acceptable at some level, and that this is not due to noise. As with the alternating segments, let us now consider whether the position of the segment has an effect of the acceptability of alternation, or whether segments in word-initial, post-vocalic, and post-consonantal all pattern the same way.

To test for position effects in exceptional segments (*hypothesis 2b*), I ran a three (position: word-initial vs. post-consonantal vs. post-vocalic) by two (allophone: expected vs. variant) repeated-measures ANOVA on the ratings of exceptional segments. The results revealed main effects of both position ($F(2, 72) = 40.481$, $p < .001$) and allophone ($F(1, 73) = 767.518$, $p < .001$), as well as a significant interaction between the two ($F(2, 72) = 57.094$, $p <.001$). As seen in Figure 17, this interaction is the result of a higher rate of acceptability of the variant form in post-consonantal position. The results of paired *t*-tests comparing exceptional segments in their variant forms in post-consonantal context with those in word-initial and post-vocalic contexts confirm this (($t(73) = 11.155$, p < .001) and ($t(73) = 10.311$, p < .001), respectively).

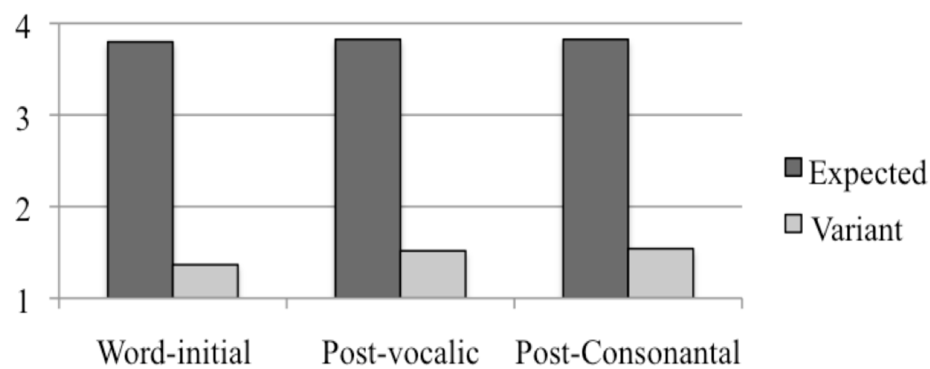
Figure 17. Variation in exceptional segments



I used the mean and standard deviation of all of the exceptional segments, and found that averages of all but one condition fell within two standard deviations of the mean. The condition for which this was the case was the post-consonantal exceptional /f/. Recall that this is the one condition in the experiment that contained only one root (whereas all others had either two or four). This means that the unusually high acceptance rate for the variant form of exceptional /f/ could be due to a lexical effect of this particular root, or maybe the fact that there are no other roots containing exceptional /f/ in this position.

Looking at exceptional segments in post-consonantal context, excluding the root /tlfn/, the results revealed a significant but relatively weaker effect of position ($F(2, 72) = 3.909$, $p = .024$) and a strong effect of allophone ($F(1, 73) = 845.695$, $p < .001$). The interaction of position and allophone was not significant ($F(2, 72) = 1.528$, $p > .05$). Average scores for exceptional segments, excluding the root /tlfn/, appear in Figure 18. For the most part, variation in exceptional segments does not show as clear a position effect as variation in alternating segments.

Figure 18. Variation in exceptional segments, /tlfn/ excluded

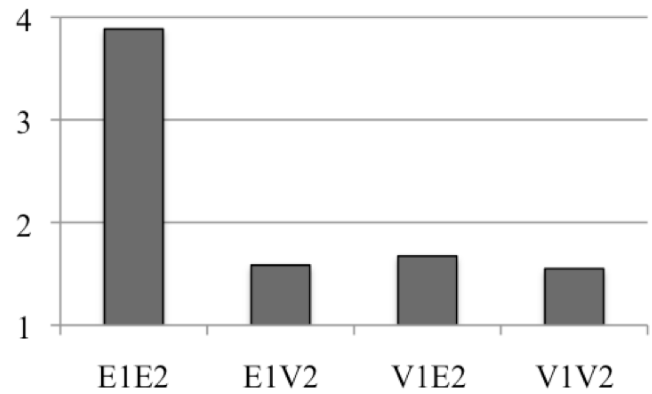


3.3.4 Variation in Roots Containing Multiple Segments

Recall that *hypothesis 3a* in Table 37 predicts that words containing two alternating segments in their variant forms should not be deemed acceptable. This is based on the predictions made by the different rankings in the OT analysis summarized in Table 36 which allow for words containing at least one alternating segment in its expected form, but not words which contain two alternating segments in their variant forms.

A one-sampled *t*-test comparing participants' raw ratings of these words with 1.5 (the mid-point between the two lowest ratings possible in the task), did not reveal a significant difference ($t(73) = .659$, $p > .05$). Unlike the predictions made in Table 37, a paired *t*-test comparing z-scores of participants' ratings of words containing two variant forms with those containing one variant form revealed that there was not a significant difference ($t(74) = .308$, $p > .05$). This means that participants rated words containing two alternating segments similarly whether they contained one or two variant segments. This is seen in Figure 19, where words containing the two target segments in their expected words (E1E2) are much more acceptable than words with only one segment in its expected form (E1V2 or V1E2) and words with two segments in their variant forms (V1V2).

Figure 19. Words containing two alternating segments



Hypothesis 3b predicts that the acceptability of variant forms of alternating segments in hybrid words will be similar to variant forms of the same segment type in words containing only one target segment. To test this hypothesis, I ran a paired *t*-test comparing subjects' average scores of non-hybrid words containing the variant form of an alternating segment with that of hybrids with the exceptional segment in its expected form and the alternating segment in its variant form. The results showed that there is not a significant difference between the two groups ($t(73) = .391$, $p > .05$). This result supports the analysis of alternating segments in hybrid words maintaining the ability to alternate (and allowing for some variation).

Similarly, *hypothesis 3c* predicts that the acceptability of variant forms of exceptional segments in hybrid words will be similar to variant forms of exceptional segments in words containing only one target segment. To test this hypothesis, I ran a paired *t*-test comparing subjects' average scores of non-hybrid words containing the variant form of an exceptional segment with that of hybrids with the alternating segment in its expected form and the exceptional segment in its variant form. The results showed a significant difference between the two groups, with exceptional variants in hybrids being less acceptable ($t(73) = 11.839$, $p < .001$). Contrary to *hypothesis 3c*, it was found that variant forms of exceptional segments are more acceptable in words containing only one target segment than in hybrid words containing two target segments.

3.4 Chapter Summary

In this chapter, I have discussed the implementation and results of a perception study examining the acceptability of variation in several aspects of Modern Hebrew spirantization. Seventy-four native speakers of Hebrew were asked to rate the naturalness of words containing expected and variant forms of alternating and exceptional segments in a web-based acceptability rating task.

The results show that, although variation is acceptable in alternating segments, variant forms are deemed less acceptable than expected forms. Furthermore, variation is more acceptable in words containing one alternating form than those containing one exceptional segment. Additionally, it was found that the position of the segments within the word matters. In post-consonantal context, alternating segments show higher ratings of acceptability of variant forms than in other contexts. A closer analysis of segments in this context shows that participants disprefer the variant form when it results in two adjacent stops in word-medial position. In words containing two alternating segments, the results showed that the lowest acceptability rating was given to words with two variant forms, but participants rated these same words with only one variant similarly unacceptable. In hybrid forms, alternating segments in their variant form were rated equally acceptable as those in words containing only one target segment, whereas variation in exceptional segments in hybrids was deemed less acceptable than in words containing the exceptional segment as the only target segment. The OT analysis in the following chapter will take into account the different aspects presented in these results.

4 Analysis – The Combined Model

In Chapter 3, I described a rating task that measured participants' acceptance of variation in alternating and exceptional segments in Modern Hebrew spirantization. The Optimality Theory (OT) analysis presented in this chapter accounts for the results of the rating task, including gradience in the acceptability of variation. The experiment found that, although some level of variation was acceptable in both alternating and exceptional segments, variation in alternating segments was significantly more acceptable. This means that, even though exceptionality is not categorical in Modern Hebrew spirantization, speakers still distinguish between exceptional and alternating segments.

I use these results as the starting point for an analysis of exceptionality and variation as two sources of non-conformity, and investigate different ways of accounting for these in phonology. In doing this, I show that while some approaches are capable of accounting for alternation and exceptionality or alternation and variation, no one approach is capable of handling alternation and both sources of non-conformity on its own.

The final model combines two existing approaches – it extends set-indexation (Pater 2000) to account for exceptionality at the segmental level and uses Stochastic OT (Boersma 1998, Hayes & MacEachern 1998, Zuraw 2000, Boersma & Hayes 2001) to account for variation. By making use of these innovations, I will demonstrate that the combined model is better able to account for these two sources of non-conformity when they occur in a single phenomenon.

Section 4.1 summarizes the analysis of alternation presented in Section 2.7.1. In Section 4.2, I explain why exceptionality in spirantization must be encoded at the segmental level, and in Section 4.2.1, I discuss the rationale behind using and extending set-indexation (Pater 2000). In Section 4.2.2, I consider two other approaches to exceptionality (Inkelas et al. 1997, Itô & Mester 1999). In Section 4.3, I review the evidence that variation in Modern Hebrew spirantization is gradient and probabilistic, and in Section 4.3.1, I turn to Stochastic OT (Boersma 1998, Hayes & MacEachern 1998, Zuraw 2000, Boersma & Hayes 2001) and explain how the Gradual Learning Algorithm handles gradient, probabilistic variation. In Section 4.3.2, I consider an alternative account of Modern Hebrew spirantization as a variable grammar (Adam 2002). Section 4.4 closes the chapter with a comprehensive analysis of Modern Hebrew spirantization using a model that combines set-indexation and Stochastic OT.

4.1 Analysis for Allophony in Modern Hebrew Spirantization

As a starting point for the account, this section briefly reviews the analysis of alternation in Modern Hebrew spirantization outlined in Section 2.7.1. Modern Hebrew spirantization is a phenomenon in which segments are realized as fricatives in post-vocalic contexts and stops in word-initial and post-consonantal contexts. As a result, the relevant constraints refer to the feature [continuant] as well as to stops and fricatives. Given the distribution of stops and fricatives, the constraints *V-STOP, which prohibits post-vocalic stops, is essential to the analysis. The context-free constraints *[+cont, -sib] and *STOP, and the faithfulness constraint IDENT-IO[cont], are also used.

(17) Constraints for the analysis of alternation

***V-STOP**	Post-vocalic stops are prohibited.
***[+cont, -sib]**	Non-sibilant fricatives are prohibited.
***STOP**	Stops are prohibited.
IDENT-IO[cont]	Input-output correspondents are identical in [±cont].

The contextual markedness constraint *V-STOP must dominate the faithfulness constraint IDENT-IO[cont] to prevent stops from surfacing following a vowels regardless of whether the input segment is a stop. *V-STOP must also dominate *[+cont, -sib] so that fricatives are preferred only in post-vocalic contexts, and stops are preferred elsewhere. The context-free markedness constraint *[+cont, -sib] must also dominate IDENT-IO[cont] to allow input fricatives to be realized as stops in word-initial and post-consonantal contexts. The context-free markedness constraint *STOP must be ranked below *V-STOP and *[+cont, -sib], but is unranked with respect to IDENT-IO[cont]; its role will become clear in the analysis of variation presented in Section 4.3. The ranking of these constraints is in (18). This ranking yields the same output regardless of whether the alternating segments correspond to stops or fricatives in the input. However, for the purposes of consistency in the evaluation, I assume stops to be the input for alternating segments.

(18) Constraint ranking for alternation

***V-STOP » *[+cont, -sib] » IDENT-IO[cont], *STOP**

The tableaux in Table 42 demonstrate how this constraint ranking accounts for alternation. The root /bkh/ contains two alternating segments: /b/, which is realized as the fricative [v] in post-vocalic context and as the stop [b] elsewhere, and /k/, which is realized as the fricative [χ] in post-vocalic context and as the stop [k] elsewhere.

Table 42. Alternation in the root /**bk**h/

Input	Output	*V-STOP	*[+cont, -sib]	IDENT-IO[cont]	*STOP
/bkh/ + (inf.) *'to cry'*	☞a. livkot		*	*	**
	b. libkot	*!			***
	c. livχot		**!	**	*
	d. libχot	*!	*	*	**
/bkh/ + (3p.past) *'cried'*	☞a. baχa		*	*	*
	b. baka	*!			**
	c. vaχa		**!	**	
	d. vaka	*!	*	*	*

In the tableaux above, the winning candidates are those containing two segments that conform to the spirantization distribution. For the form in the first tableau ([livkot]) this translates to a post-vocalic [v] and a post-consonantal [k]. For the form in the second tableau ([baχa]) this translates to a word-initial [b] and post-vocalic [χ]. Candidates (b) and (d) in both tableaux incur fatal violations of *V-STOP for containing a post-vocalic stop, whereas candidate (c) incurs two violations of *[+cont, -sib] for containing two fricatives, one of which is not driven by *V-STOP.

4.2 Exceptionality at the Segmental level

Recall that in Section 2.4.1, I argued that exceptionality in Modern Hebrew spirantization must be encoded at the segmental level, rather than the word or root level. This was based on the existence of 'hybrid' words, which contain both alternating and exceptional segments. Thus, the presence of an exceptional segment in a given root does not preclude the presence of an alternating one in the same root, so different conjugations of a hybrid root have an exceptional segment alongside an alternating one. An example of such a root – /kbr/ ('to bury'), which contains a non-alternating /k/ (which behaves exceptionally in post-vocalic contexts, underlined) and an alternating /b/ (bolded) is given in Table 43.

Table 43. Conjugations for hybrid root /k̲**b**r/ - *'to bury'*

Past		Singular	Plural
1st		[k̲aˈ**v**arti]	[k̲aˈ**v**arnu]
2nd	masc	[k̲aˈ**v**arta]	[k̲aˈ**v**artem]
2nd	fem	[k̲aˈ**v**art]	[k̲aˈ**v**arten]
3rd	masc	[k̲aˈ**v**ar]	[k̲a**v**ˈru]
3rd	fem	[k̲a**v**ˈra]	

Present	Singular	Plural
masculine	[k̲oˈ**v**er]	[k̲o**v**ˈrim]
feminine	[k̲o**v**eˈret]	[k̲o**v**ˈrot]

Future		Singular	Plural
1st		[ek̲ˈ**b**or]	[nik̲ˈ**b**or]
2nd	masc	[tik̲ˈ**b**or]	[tik̲**b**eˈru]
2nd	fem	[tik̲**b**eˈri]	
3rd	masc	[jik̲ˈ**b**or]	[jik̲**b**eˈru]
3rd	fem	[tik̲ˈ**b**or]	

Lexical approaches to exceptionality are unable to account for roots like /kbr/ because they do not allow the segments within a word to behave differently from one another with respect to conformity to a given phenomenon. In my analysis of spirantization, I extend the set-indexation approach (Pater 2000), originally developed to account for category-specific or item-specific effects to the segmental level, thus enabling it to account for exceptional segments. I explain how this is done in Section 4.2.1, after which I discuss two alternative approaches to exceptionality and their inability to account for the facts of Modern Hebrew spirantization.

4.2.1 Extending set-indexation

Recall from Section 2.7.2 that set-indexation (Pater 2000) accounts for exceptionality by assigning exceptional words to different sets. In his account of English secondary stress, for example, Pater separated words into three such sets: those in which secondary stress always falls on the syllable with the primary stress in the stem, exceptional words in which it systematically does not, and those in which secondary stress is variable.

Another important aspect of this approach is the indexing of constraints to these sets. Each set can have its own collection of set-specific constraints as needed, and only words belonging to a specific set can incur violations of the constraints indexed to that set. However, all words could incur violations of the general (i.e. not set-indexed) constraints. As a result, words in the non-indexed set only incur violations of the general constraints. Set-indexed and general constraints are ranked in the same grammar, allowing set-indexed and non-indexed words to behave differently depending on the relative ranking of all of the constraints.

Alternation in Modern Hebrew spirantization is derived by ranking the relevant markedness constraints above the faithfulness constraint for the feature [continuant]. In set-indexation, exceptional segments are assigned membership in a set (Set 1) whose corresponding faithfulness constraint (IDENT-IO[cont]$_1$) is ranked above the markedness constraints driving spirantization. As a result, exceptional segments occur faithfully in the output, while alternating segments, which are not subject to the set-indexed faithfulness constraint, occur in the output as dictated by markedness. A schema of the ranking of these constraints in Modern Hebrew appears in Figure 20.

Figure 20. Schema for exceptionality and alternation using set-based approach

IDENT-IO[cont]$_1$	**»**	**Markedness constraints** *V-STOP, *[+cont, -sib]	**»**	**IDENT-IO[cont]**
Prohibits alternation in exceptional segments		*Determines the distribution of stops and fricatives in alternating segments*		

Extending Pater's (2000) set-indexation to the segmental level allows for the encoding of exceptionality at different levels of grammatical structure using a single mechanism. Set-indexation has already been extended from its original use for exceptional words (Pater 2000) to exceptional morphemes (Pater 2006). Pater (2006) uses morpheme set membership and set-indexed faithfulness and markedness constraints to account for syncope in Yine (formerly known as Piro) and allomorphy in Finnish. The flexibility of the set-indexation approach not only enables it to account for exceptionality at distinct levels of grammatical structure, but I posit that it allows different elements (segments, roots, morphemes, words, etc.) that are exceptional with respect to a specific phenomenon to be members of the same set. Importantly, it gives learners the flexibility to determine the level at which an exception is encoded. This is discussed further in Section 5.2.

In the tableaux in Table 44, we return to the root /bkh/ from Table 42, which contains two alternating segments. Since alternating segments are not members of the exceptional set, the ranking of IDENT-IO[cont]$_1$ above the markedness constraints driving spirantization does not affect selection of the outputs. Rather, violations of the markedness constraints determine the winning candidates: [livkot], with a fricative [v] in post-vocalic context and a stop [k] in post-consonantal context, and [baχa], with a stop [b] in word-initial context and a fricative [χ] in post-vocalic context.

Table 44. Alternating segments unaffected by set-indexed constraint

Input	Output	IDENT-IO[cont]$_1$	*V-STOP	*[+cont, -sib]	IDENT-IO[cont]	*STOP
/bkh/ + (inf.) *'to cry'*	☞a. livkot			*	*	**
	b. libkot		*!			***
	c. livχot			**!	**	*
	d. libχot		*!	*	*	**
/bkh/ + (3p.past) *'cried'*	☞a. baχa			*	*	*
	b. baka		*!			**
	c. vaχa			**!	**	
	d. vaka		*!	*	*	*

The roots in Table 45 and Table 46 contain exceptional segments in them, making crucial the ranking of IDENT-IO[cont]$_1$ above the markedness constraints driving spirantization. In Table 45, the root /χps/ contains two exceptional segments: /χ/ in root-initial position and /p/ in root-medial position. These segments are both indexed to Set 1, making them subject to the faithfulness constraint IDENT-IO[cont]$_1$. Since IDENT-IO[cont]$_1$ is ranked above the markedness constraints driving spirantization, candidates in which the underlying fricative /χ/ corresponds to a stop [k] in the output and/or the underlying /p/ corresponds to a fricative [f] in the output incur violations of IDENT-IO[cont]$_1$. As a result, only the fully faithful candidates occur in the output in such cases.

Table 45. Words containing two non-alternating, exceptional segments (Set 1)

Input	Output	IDENT-IO[cont]$_1$	*V-STOP	*[+cont, -sib]	IDENT-IO[cont]	*STOP
/$\chi_1$$p_1$s/+(3p.past) *'looked for'*	☞a. χ_1i$p_1$es		*	*		*
	b. k_1i$p_1$es	*!	*		*	**
	c. χ_1i$f_1$es	*!		**	*	
	d. k_1i$f_1$es	*!*		*	**	*
/$\chi_1$$p_1$s/+(inf.) *'to look for'*	☞a. leχ_1a$p_1$es		*	*		*
	b. lek_1a$p_1$es	*!	**		*	**
	c. leχ_1a$f_1$es	*!		**	*	
	d. lek_1a$f_1$es	*!*	*	*	**	*

The examples in Table 45 are compatible with indexation at the level of the morphological root. However, the hybrid root /bχr/ in Table 46 which contains an alternating /b/ and an exceptional /χ/, is not. Unlike the examples in Table 45, set membership is only assigned to one of the target segments (namely, the exceptional /χ/). This being the case, the /b/ alternates as dictated by markedness, surfacing as the stop [b] in word-initial context in [baχar], and the fricative [v] following a vowel in [livχor]. However, due to the ranking of IDENT-IO[cont]$_1$ above the markedness constraints driving spirantization, the exceptional segment occurs as the fricative [χ] regardless of its context. Most importantly, the ranking rules out (81c), where the velar obstruent is realized as a stop following a consonant.

Table 46. Hybrid words with one non-indexed segment and another from Set 1

Input	Output	IDENT-IO[cont]$_1$	*V-STOP	*[+cont, -sib]	IDENT-IO[cont]	*STOP
/bχ_1r/ + (inf.) *'to choose'*	☞a. liv$\chi_1$or			**	*	
	b. lib$\chi_1$or		*!	*		*
	c. liv$k_1$or	*!		*	**	*
	d. lib$k_1$or	*!	*		*	**
/bχ_1r/ + (3p.past) *'chose'*	☞a. ba$\chi_1$ar			*		*
	b. ba$k_1$ar	*!	*		*	**
	c. va$\chi_1$ar			**!	*	
	d. va$k_1$ar	*!	*	*	**	*

Extending set membership to the segmental level thus allows for an indexation-based analysis of hybrid words, such as those in Table 44. If exceptionality were only encoded at the word level, /b/ and /χ/ would have to either both be exceptional, deriving *[libχor] and [baχar], or both alternating, deriving *[livkor] and [baχar].

In Section 4.2.2, I consider two alternative approaches to exceptionality and problems they face in handling the data discussed in Chapter 3. I then turn to Section 4.4, to the combined model and its ability to account for both exceptionality and variation.

4.2.2 Other approaches to Exceptionality

This section reviews two other theoretical accounts of exceptionality: one which treats exceptionality as a word-level phenomenon (Itô & Mester 1999) and another which treats it as a segmental-level phenomenon (Inkelas et al. 1997). After describing each approach, I will provide examples of how these approaches would handle certain data presented in Chapter 3.

4.2.2.1 **Stratal Classification of Exceptions**

Itô and Mester (1995, 1999) propose an internal stratal classification of Japanese loanword phonology. This four-tiered stratification includes native (Yamato) words, Sino-Japanese loans, Western loans, and Mimetic items in a core-periphery structure. This structure contains native words at the core, followed by established loans on the first peripheral tier, assimilated foreign words on the next tier, and unassimilated foreign words on the outermost tier. Each tier has a corresponding ranking of faithfulness. For the constraints under consideration, the innermost tier corresponds to a ranking of markedness above all faithfulness constraints and the outermost tier corresponds to a ranking of faithfulness above all markedness constraints. Moving outward from the core, each successive tier's faithfulness constraint is promoted above at least one markedness constraint from the faithfulness constraint corresponding to the tier below it.

In Table 47 we see how a non-native word—the English word 'city'—would be pronounced as a member of different strata. The two markedness constraints, *SI and *TI, force palatalization of the syllables [si] and [ti] to [ʃi] and [tʃi], respectively. When indexed to the most native-like stratum (stratum Z), both syllables are palatalized (resulting in [ʃitʃi]), due to the ranking of the two markedness constraints above the corresponding faithfulness constraint. In the middle stratum (stratum Y), whose corresponding faithfulness is ranked between the two markedness constraints *SI and & *TI, the winning candidate, [ʃiti], contains the palatal [ʃ] while the palatalization of [t] is suppressed. This is made possible here by the use of two distinct markedness constraints for which the repair would be palatalization. However, when the word is indexed for the most unassimilated stratum (stratum X) the fully faithful candidate [siti] wins because the ranking of the markedness constraints below the corresponding faithfulness constraints prevents palatalization and enforces a faithful realization of the two consonants.

Table 47. Sample tableaux for 'city' from Itô and Mester (1999)

Input	Output	**FAITH /X**	***SI**	**FAITH /Y**	***TI**	**FAITH /Z**
/siti/ [stratum Z]	☞ [ʃitʃi]					**
	[ʃiti]				*!	*
	[siti]		*!		*	
	[sitʃi]		*!			*
/siti/ [stratum Y]	[ʃitʃi]			**!		
	☞ [ʃiti]			*	*	
	[siti]		*!		*	
	[sitʃi]		*!	*		
/siti/ [stratum: X]	[ʃitʃi]	**!				
	[ʃiti]	*!			*	
	☞ [siti]		*		*	
	[sitʃi]	*!	*			

Although the stratal approach lends itself to distinctions in loanword phonology, it is not a necessary precursor for its application. Applying this approach to Modern

Hebrew, however, we could assume that historically merged and degeminated segments from Tiberian Hebrew occupy one stratum, while the more recent borrowings form another stratum. Treating all exceptional segments in Modern Hebrew as borrowed is not entirely implausible. Modern Hebrew, in the earliest days of its revival, was a structured language, not native to any of its speakers. It could be claimed, then, that all lexical items were in essence 'borrowed', and that some regularly adhere to phonological rules whereas others do not (for either preservation of contrast or to maintain its phonology from the language of origin). However, since all exceptional segments behave similarly, rather than grouping words or segments in Modern Hebrew by their language of origin, as is done in Japanese, members of a tier would be grouped according to the pattern they display. Table 48 demonstrates this difference in patterning.

Table 48. Stratification of exceptions in Japanese and Modern Hebrew

Japanese (Itô and Mester 1999)		**Modern Hebrew**	
Yamato	Native	Alternating	Native (from Tiberian Hebrew)
Sino-Japanese	Established Loans	v (<*w), χ (<*ħ), f (borrowed)	Non-alternating Fricatives
Foreign	Assim. Foreign	k (<*q), degeminated stops	Non-alternating Stops
Mimetic	Unassim. Foreign		

Assuming the strata used above for Modern Hebrew, the tableaux in Table 49 illustrate how this analysis would handle words with an exceptional stop (as in A), words with an exceptional fricative (as in B), and words with alternating segments (as in C). For each stratum, there would be a corresponding ranking of IDENT[cont]. Words containing exceptional stops, which violate *V-STOP when they follow a vowel, would be placed in the stratum with the highest ranking of faithfulness (stratum X) to avoid spirantization. This would allow the exceptional candidate in A ([dakar]) to be selected, with a post-vocalic stop, over the candidate that conforms to the spirantization distribution ([daχar]). In B, the exceptional candidate ([χalam]) would be the winner since the corresponding faithfulness constraint for stratum Y is ranked above *[+cont, -sib], for which the optimal candidate incurs a violation. Note that this ranking predicts that if exceptional stops occur, so do exceptional fricatives, but not necessarily the reverse. In C, the input contains two alternating segments, indexing it for Stratum Z, with the corresponding faithfulness constraint ranked below the two markedness constraints driving spirantization. The winning candidate ([livkot]), then, is selected by these markedness constraints.

Table 49. Tableaux for Modern Hebrew using tiers and the core-periphery structure

	Input	Output	**IDENT-IO [cont] /X**	***V-STOP**	**IDENT-IO [cont] /Y**	***[+cont, -sib]**	**IDENT-IO [cont] /Z**
A	/dkr/ + (3p.past)	☞a. dakar		*			
	'poked, stabbed'	b. daχar	*!				
	[stratum: X]						
B	/χlm/ + (3p.past)	☞a. χalam				*	
	'dreamed'	b. kalam			*!		
	[stratum: Y]						
C	/bkh/ + infinitive	☞a. livkot				*	*
	'to cry'	b. libkot		*!			
	[stratum: Z]	c. livχot				**!	**
		d. libχot		*!		*	*

Since the exceptional fricatives in B do not incur any violations of *V-STOP, the two exceptional strata could also be merged into a stratum whose corresponding faithfulness constraint is ranked above both markedness constraints, creating only two strata – one for alternating segments and another for exceptional segments. However, the stratal approach is not suitable to account for hybrid words in Modern Hebrew, in which the alternating segment and exceptional segment occur in the same context. As I illustrate below, in these cases, the hybrid word would have to be indexed to more than one stratum, which is problematic.

The tableaux in Table 50 include two forms of the hybrid root /bkr/ ('to visit'), with an alternating /b/ and a non-alternating /k/ (which behaves exceptionally in post-vocalic context. In these tableaux, we see that the root does not pattern with a single stratum and that situating it in one or the other does not allow both optimal candidates ([mevaker] and [biker]) to occur in the output as a result of a single ranking. While placement in stratum X, with the ranking of the corresponding faithfulness constraint above *V-STOP, allows the optimal candidate ([biker]) to surface in A, there is not a single stratum that would yield the correct optimal candidate ([mevaker]) in B. The reason for this is that the optimal candidate contains both a fricative and a stop in post-vocalic position. This means that, if the word is indexed for stratum X, with the ranking of the faithfulness constraint above *V-STOP, it would result in the surfacing of candidate b ([mebaker]) with two post-vocalic stops. Likewise, placement in stratum Y, with the corresponding faithfulness constraint below *V-STOP and above *[+cont, -sib], would result in the selection of candidate c ([mevaχer]), with two fricatives.

Table 50. Tableaux for Modern Hebrew hybrids using strata

	Input	Output	IDENT-IO [cont] /X	*V-STOP	IDENT-IO [cont] /Y	*[+cont, -sib]	IDENT-IO [cont] /Z
A	/bkr/ + (3p.past) *'visited'* [stratum:X]	☞a. biker		*		*	
		b. viker	*!	*	*	**	
		c. biχer	*!		*	*	
		d. viχer	*!*		**		
B	/bkr/ + (pres. m.) *'visits'* [stratum:?]	a. mevaker	*(!)	*(!)	*	*	*
		💣b. mebaker (X)		*(!)*			
		💣c. mevaχer (Y)	*(!)*		**	**	**
		d. mebaχer	*(!)	*(!)	*	*	*

Hybrid words therefore illustrate the need for a mechanism that allows exceptionality to be encoded at the segmental level. While stratal indexation of exceptions is similar to set-indexation in many respects, expanding this approach to the segmental level would require that segments, rather than words be indexed to specific strata. I will now consider a second alternative approach to exceptions, one that makes use of ternary feature specification and prespecification.

4.2.2.2 **Ternary Features and the Prespecification Approach**

In this section, I summarize the prespecification approach proposed by Inkelas, Orgun, and Zoll (1997) and relate it to Idsardi's (1997) classification of opacity in Hebrew [k] and [χ]. I then demonstrate how the prespecification approach would handle alternation, exceptionality, and hybrid words in Modern Hebrew.

Inkelas, Orgun and Zoll (1997) provide an analysis of labial attraction and coda devoicing in Turkish, both of which have exceptions. Alternating segments are underspecified for the relevant feature – vowel roundness or voicing in coda consonants. Using underspecification and prespecification, this approach avoids creating co-phonologies, or distinct phonological grammars, such as the lexical strata with constraint reranking approach, among others. Since alternating segments are not specified for the relevant feature in the input but are assumed to be fully specified in the output, alternating segments always incur a violation of faithfulness. This is because in this approach IDENT[F] is assumed to be symmetrical – incurring equal violations for any change of value for [F] (i.e. whether a specified value changes from + to -, - to +, or an unspecified segment acquires a specification for [F]). The constraint is defined in (19).

(19) Definition of feature identity

IDENT[F] Let α be a segment in S1 and β be a correspondent of α in S2. If α is [γF], then β is [γF]. (McCarthy & Prince 1995)

Exceptional segments are specified for the relevant feature in the input and incur a violation of faithfulness only in cases where the value for that feature in the output does not correspond to the value in the input. This is schematized in Table 51 for the segments [t] and [d], allowing for an exceptional (non-alternating) [d], and non-alternating [t], and an alternating segment which surfaces as [t] or [d] depending on context. The tableaux in Table 52 demonstrate how this distinction bears on coda devoicing in Turkish.

Table 51. Schema for constraint violation by different segments

	Input	**Output**	**IDENT[voice]**
Exceptional 1	/d/ | [+voice]	[t]	*
		[d]	✓
Exceptional 2	/t/ | [-voice]	[d]	*
		[t]	✓
Alternating	/D/	[d]	*
		[t]	*

In this approach, faithfulness dominates the relevant markedness constraints. Alternating segments incur equal violations of faithfulness, allowing the markedness constraints to determine the value for the relevant feature, while the winning output for exceptional segments is the fully faithful candidate.

This is seen in Table 52, in an example from coda devoicing in Turkish (Inkelas et al 1997). In this phenomenon, stops that are voiced in onset position are voiceless in coda position. The input in A contains an unspecified alternating stop, represented by the letter 'D', which surfaces as [t] in coda position (and [d] in onset position, not shown). The two candidates, [kanat] and [kanad], incur violations of IDENT[voice] because both are assumed to be fully specified for voicing in the output. The candidate with a voiced coda, [kanad], violates the coda devoicing constraint. The winning candidate, then, is [kanat] which undergoes coda devoicing.

The input in B is a non-alternating, exceptional /d/ which is prespecified for [+voice]. This segment does not undergo coda devoicing, but rather maintains its voicing in all positions due to the ranking of the faithfulness constraint above the markedness constraint driving coda devoicing. Since the segment is specified for [+voice] in the input, the candidate with the voiceless segment, [etyt], incurs a fatal violation of IDENT[voice], resulting in the surfacing of the fully faithful candidate [etyd].

The input in C is another non-alternating segment. In this case, it is prespecified for [-voice], which results in a voiceless stop surfacing in both onset and coda positions. Since the segment is specified for [-voice] in the input, the candidate with the voiced segment, [devled], incurs a fatal violation of IDENT[voice], resulting in the surfacing of the fully faithful candidate [devlet].

Table 52. Coda devoicing in Turkish: prespecification approach

	Input	Output	IDENT[voice]	CODA DEVOICING
A	/kana**D**/	☞a. kana**t** [-voice]	*	
		b. kanad [+voice]	*	*!
B	/ety**d**/ [+voice]	a. etyt [-voice]	*!	
		☞b. ety**d** [+voice]		*
C	/devle**t**/ [-voice]	☞a. devle**t** [-voice]		
		b. devled [+voice]	*!	*

A brief discussion of underspecification is due prior to applying this approach to Modern Hebrew spirantization. Two main assumptions of underspecification in generative phonology are those of Lexical Minimality and Full Specification. Lexical Minimality assumes that the phonological information used to distinguish lexical items must be condensed to some minimum in underlying representations, while Full Specification assumes that phonological outputs must be fully (or maximally) specified (Steriade 1995). Although Full Specification is not a necessary assumption for underspecification (cf. Itô, Mester, and Padgett (1995)), it is in line with the evaluation in Table 52, with minimal specification in the input and obligatory violation of faithfulness of the unspecified segment in the output. As characterized by Inkelas (1994), there are traditionally three categories into which underspecification principles fall: redundant features (Clements 1987, Steriade 1987, Itô & Mester 1989), unmarked material (Kiparsky 1982), and predictable material (Pulleyblank 1988, Archangeli & Pulleyblank

1989). The specification of this material, then, may be acquired during the course of the derivation. Although underspecification has drawn some criticism in recent literature as an unnecessary part of the grammar in OT (Prince & Smolensky 1993, among others), the use of ternary specification in the prespecification approach is compatible with Richness of the Base. Inkelas (1994) and Inkelas, Orgun, and Zoll (1997) argue that prespecification is necessary to capture alternations for which there are two exceptional patterns for which the three-way distinction is necessary (cf. Itô, Mester, and Padgett (1995) for other uses of underspecification).

Applying the prespecification approach to Modern Hebrew, I utilize a ternary feature distinction described in Idsardi (1997). He discusses opaque exceptional [k] (<*q) and [χ] (<*ħ) in Modern Hebrew and proposes a three-way distinction for underlying specification of the feature [continuant]. Specifically, he suggests that exceptional segments are underlyingly prespecified for this feature (as either [+cont] or [-cont]), while alternating segments are underlyingly unspecified for [continuant]. While Idsardi's classification is only for the dorsals, this three-way distinction can be extended to include the labial consonant pairs participating in Modern Hebrew spirantization, as in Table 53.

Table 53. Three-way distinction between alternating pairs, exceptional fricatives and exceptional stops

	Alternating	Exceptional Fricative	Exceptional Stop
[k] , [χ]	spirantizing /**k**/	/χ/ <*ħ	/k/ <*q
[p] , [f]	spirantizing /**p**/	/f/ (from borrowings)	/p/ (from geminates)
[b] , [v]	spirantizing /**b**/	/v/ <*w	/b/ (from geminates)
Input	**unspecified for [cont]**	**specified for [+cont]**	**specified for [-cont]**

Prespecification and underspecification are made available by the principle of Richness of the Base (Prince & Smolensky 1993) because no restrictions may be placed on the input, including whether or not features are specified. An important assumption using this approach is that outputs are always fully specified for all features, a constraint on Gen. This means that a segment lacking specification for a given feature in the input (such as alternating segments in this analysis) will incur a violation of faithfulness for that feature in acquiring a specification for it. Possible mappings that violate or obey IDENT-IO[cont] appear in Table 54. Note that alternating segments are represented with a capital letter corresponding to the IPA character for the stop, and exceptional segments are represented with their respective IPA symbol along with a specified value for the feature [continuant].

Table 54. Possible mappings that violate or obey faithfulness

Input	**Output**	**IDENT-IO[cont]**
/χ/ [+cont]	[k]	*
	[χ]	✓
/k/ [-cont]	[χ]	*
	[k]	✓
/K/	[k]	*
	[χ]	*

Bearing in mind the violations of IDENT-IO[cont] and the prespecification or underspecification of the segments in the input, the tableaux in Table 55, Table 56, and Table 57 demonstrate the selection of the expected outputs with a ranking in which IDENT-IO[cont] dominates markedness. Recall that in the analysis of allophony in

Modern Hebrew spirantization in Section 4.1, IDENT-IO[cont] was ranked lower than the markedness constraints driving the spirantization distribution. This re-ranking, combined with the underspecification of segments participating in the spirantization distribution, predicts the same outcome for allophony cases since all candidates will tie in their violations of IDENT-IO[cont]. In Table 55 we see this as applied to a root with two alternating segments. Candidates (b) and (d) in both tableaux incur fatal violations of *V-STOP. While the optimal candidates in (a) incur a violation of lower-ranked *[+cont, -sib], the candidates in (c) incur two violations of this constraint.

Table 55. Two unspecified (alternating) segments

Input	Output	IDENT-IO[cont]	*V-STOP	*[+cont, -sib]	*STOP
/**BK**h/ + (infinitive) *'to cry'*	☞a. li**vk**ot	**		*	**
	b. li**bk**ot	**	*!		***
	c. li**vχ**ot	**		**!	*
	d. li**bχ**ot	**	*!	*	**
/**BK**h/ + (3p.past) *'cried'*	☞a. **b**a**χ**a	**		*	*
	b. **b**a**k**a	**	*!		**
	c. **v**a**χ**a	**		**!	
	d. **v**a**k**a	**	*!	*	*

In Table 56, we see how this analysis handles a root with two exceptional segments, which are prespecified. In the tableau, the fully faithful candidate is selected because all others violate the highly ranked IDENT-IO[cont]. In this case, the output contains a word-initial fricative and a post-vocalic stop, both of which are exceptional with respect to the spirantization distribution.

Table 56. Two prespecified (exceptional) segments

/χ p s/ + (3p.past) [+cont] [-cont] *'looked for'*	IDENT-IO[cont]	*V-STOP	*[+cont, -sib]	*STOP
☞a. **χip**es		*	*	*
b. **kip**es	*!	*		**
c. **χif**es	*!		**	
d. **kif**es	*!*		*	*

Finally, the tableaux in Table 57 demonstrate how this analysis handles hybrid words, where one segment alternates and another does not. The root in this example begins with an exceptional /k/ and has an alternating /f/ in medial position. As a result, the /p/ that is unspecified for [cont] in the input alternates (between [p] and [f]) as dictated by markedness, while the prespecified /k/ occurs as a stop in the output regardless of its context.

Table 57. One prespecified segment, one unspecified segment – hybrid forms

Input	Output	IDENT-IO[cont]	*V-STOP	*[+cont, -sib]	*STOP
/kPʔ/ + (infinitive) [-cont] *'to freeze'*	☞a. likpo	*	*		**
	b. likfo	*	*	*!	*
	c. liχpo	**!		*	*
	d. liχfo	**!		**	
/kPʔ/ + (3p.sg.past.m) [-cont] *'froze'*	☞a. kafa	*		*	*
	b. kapa	*	*!		**
	c. χafa	**!		**	
	d. χapa	**!	*	*	*

The tableaux above establish that hybrid words could be accounted for using prespecification and underspecification in the input. In fact, combining this approach with stochastic constraint ranking (as is used in the combined model) also accounts for the variation seen in Modern Hebrew spirantization. My reason for selecting set-indexation rather than prespecification is that the latter is more limited in scope. Set-indexation lends itself to encoding exceptionality at distinct phonological levels (words, morphemes, segments) and provides for the possible extension to other levels, while prespecification only allows for the specification of feature values. Allowing the learner to use the same mechanism (set-indexation) to account for exceptionality at distinct phonological levels gives him/her flexibility, upon acquiring an exceptional form, to narrow down the 'level' of the exceptionality only when evidence has been gathered that the exceptionality must be at that level (i.e. in the case of hybrid roots – specifying exceptionality at the segmental level). This is briefly discussed in Section 5.2.

4.3 Accounting for Variation

The results of the experiments discussed in Section 2.7 and Chapter 3 show that variation is acceptable in Modern Hebrew spirantization. Moreover, they indicate that subjects' ratings of expected and variant forms are distinct, with a general preference for expected forms, and that variation is also possible in exceptional segments, but to a lesser extent. In the formal analysis of this variation, then, we must be able to account for gradience in variation, rather than free variation.

In this section, I introduce the mechanisms of Stochastic OT and the Gradual Learning Algorithm (Boersma 1998, Hayes & MacEachern 1998, Zuraw 2000, Boersma & Hayes 2001) and demonstrate the ability of the algorithm to closely mimic the frequencies of variation seen in alternating segments. I then discuss an alternative account of variation in Modern Hebrew (Adam 2002). In Section 4.4, I merge the analysis using Stochastic OT with the extension of set-indexation to account for alternation, variation, and exceptionality in a combined model.

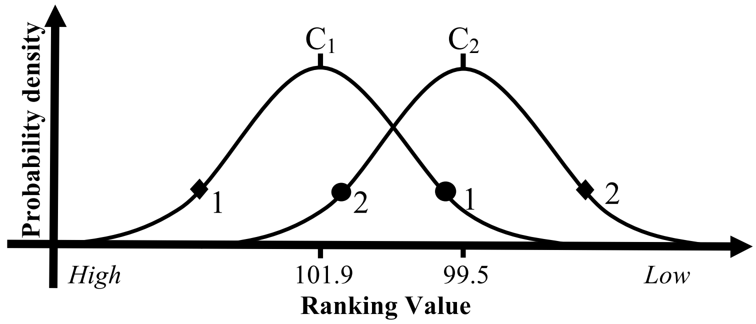
4.3.1 Variation and the Gradual Learning Algorithm

The Gradual Learning Algorithm (Boersma 1998, Hayes & MacEachern 1998, Zuraw 2000, Boersma & Hayes 2001) makes use of randomly determined constraint rankings along a continuous ranking scale to account for variation and gradience. Depending on constraint ranking values and their distributions, overlaps in the ranking distribution of constraints help to probabilistically predict variation in this error-driven learner (Boersma & Hayes 2001).

In the initial state of the algorithm, constraints are assigned a *ranking value*. Ranking values determine the position of a specific constraint with respect to other constraints along the *ranking scale*. This value may be arbitrarily set to 100 initially, as is the default in OT Soft (Hayes et al. 2003), or it may be set specifically by the user based on *a priori* assumptions (such as the ranking of markedness constraints above faithfulness constraints). Data is presented to the learner in the form of a spreadsheet containing the inputs (as heard by the learner), attested frequencies for possible outputs (*input frequency)*, and constraint violations for all tokens. An *error-driven learner,* the algorithm learns the data and makes adjustments to the constraint ranking values when there is a mismatch between the constraint ranking required for an attested form and the one generated by the algorithm.

In Stochastic OT, constraints are not only ranked with respect to other constraints, but have ranges of possible values, or *ranking distributions*, which may overlap with those of other constraints. Overlapping ranking distributions account for the possibility of variation due to constraint interaction. For each stage of the learning process, the algorithm assigns a low level of *plasticity*, or noise, to the constraint rankings, accounting for possible errors in listener data. An important characteristic of these ranking distributions in the GLA is their uniformity across all constraints; all constraint distributions have identical standard deviations since the plasticity is not a function of each individual constraint, but rather of the evaluation of all constraints. The overlap between constraints determines the *selection point* for each constraint for a given learning trial. A selection point is defined as any given point within a constraint's range or distribution on the constraint ranking scale. Variation is a result of the interaction of selection points — when a selection point for a given constraint has a value that is higher than the selection point of a constraint with a higher ranking value, it selects a candidate that is less frequently attested in the language. In Figure 21, we see an example of two constraints with distinct ranking values (101.9 for C_1 and 99.5 for C_2). The ranking distributions for these two constraints overlap, allowing for variation based on the selection points generated for each of the constraints for a given candidate.

Figure 21. Two overlapping constraints and their ranking distributions



Constraints are sorted on the ranking scale in descending value based on the selection points generated for each of the constraints (for a given underlying form). Selection points (marked $\blacklozenge_1$ and $\blacklozenge_2$ for generation 1, and $\bullet_1$ and $\bullet_2$ for generation 2) determine the constraint ranking for a given cycle of a learning task. These can vary from cycle to cycle. In generation 1, the selection point for C_1 ($\blacklozenge_1$) is higher on the ranking scale than the selection point for C_2 ($\blacklozenge_2$). This results in C_1 dominating C_2. However due to the overlap in ranking distributions, we see that in generation 2, the selection point for C_2 ($\bullet_2$) is ranked higher than the selection point for C_1 ($\bullet_1$) – a less common ranking due to the relatively small amount of overlap between the two distributions.

Once the constraint ranking has been determined for a given learning trial, the algorithm tests its ability to generate the correct output for a given underlying representation. Since the algorithm is error-driven, it refines constraint rankings when there is a mismatch between the attested form and the output derived by the learning algorithm. In Table 58, we see the start of a cycle of comparison between attested forms (learning data, candidate a) and the learner's output (candidate b). In this representative grammar, the algorithm selects the wrong winning candidate (denoted by 💣) based on its constraint ranking at this point in the learning process (adapted from Boersma and Hayes 2001). Note that constraint violations in parentheses signify equal violations for both candidates with respect to a given constraint.

Table 58. A mismatch between the learner's form and the attested form

/underlying form/	C_1	C_2	C_3	C_4	C_5	C_6
a. candidate a (attested form)	*!	*(*)	(*)		*	
💣b. candidate b (learner's output)		(*)	(*)	*		*

In this situation, the constraint violations incurred by both candidates are removed from the tableau (mark cancellation) because they would not affect the results (Tesar & Smolensky 1998). Next, adjustment of the constraints begins. Since the ranking values and distributions for the constraints are considered over all attested forms presented to the algorithm, slight adjustments are made to all constraints violated by one of the candidates – the ranking value of constraints violated by the attested form are slightly decreased, while the ranking value of constraints violated by the learner's output are slightly increased.[23] These adjustments are made so that the next time the learner is presented with the same underlying form, it will be more likely to select the attested form. The adjustment is illustrated in Table 59.

[23] The amount of adjustment is dependent on the plasticity (noise) value set for the algorithm. This value is usually very low, allowing for only small adjustments in each learning trial.

Table 59. Adjustments of ranking values

/underlying form/	C_1	C_2	C_3	C_4	C_5	C_6
a. candidate a (attested form)	*→	*→			*→	
💣b. candidate b (learner's output)				←*		←*

The algorithm cycles through these learning trials multiple times and, in its final state, takes into account all attested forms and continues to generate selection points and check the resulting rankings against all learning data to make adjustments to the constraints' ranking values until it is capable of accounting for the attested forms. In the case illustrated above, this means that the constraint C_4, and/or possibly C_6, will eventually achieve a ranking value that is higher than C1, C2, and C5, allowing less possibility for candidate b to occur in the output.

The scenario I have described holds true for underlying forms with only one attested output. The GLA, however, is also capable of accounting for variation by generating selection points and making adjustments to ranking values. In cases of variation, the probability of multiple output forms causes stochastic variations in the constraint ranking values, leading the algorithm to mimic the attested frequency of variants in the language. A similar mechanism is used in the adjustment stage of learning variation – the attested variant with the highest frequency will carry more weight than the other variants in determining the final ranking values for the constraints.

The GLA was applied to the data from the experiment in Chapter 3. In this application I first included only roots containing alternating segments, so as to test the algorithm's ability to match the frequencies of variation in these forms before introducing exceptions to the learner.

I was also interested in seeing whether the addition of a constraint prohibiting two adjacent segments with the feature [-cont] would improve the performance of the learner. Support for positing such a constraint comes from the results in Chapter 3, where in post-consonantal context, fricatives (the variant form) were rated more acceptable than stops (the expected form according to the spirantization distribution) in the experiment. The prohibition of adjacent stops is justified by acoustic data pointing to a deficit of perceptual cues in unreleased stops (since these cues are usually present in the CV transition), some of which are present in the fricative noise transition when a stop is followed by a fricative (Wright 2004). All roots containing exceptional segments (including hybrids) were excluded from the learning runs discussed in this section. Those will be discussed in Section 4.4. In total, two runs were generated. The first run contained the original set of constraints for spirantization (*V-STOP, *[-cont, -sib], IDENT-IO[cont], and *STOP), and the second run contained the additional constraint against adjacent stops, *STOPSTOP.

Using OT Soft to calculate these two runs, the same parameters were used for both. All constraint ranking values were initially set to 100, there were a total of 40,128 learning trials with plasticity set to an initial value of 2 and a final value of 0.002. Constraint ranking values found in both runs are in Table 60. The derived values for the four constraints used in both were very similar in the two runs, with identical ranking values for *[+cont, -sib] and IDENT-IO[cont]. Additionally, the ranking values for all constraints, including *STOPSTOP in the second run, are very close to each other, allowing for considerable overlap in their selection points.

Table 60. Summary of ranking values (alternating only)

Run 1		**Run 2**	
*V-STOP	102.956	*V-STOP	102.902
*[+cont, -sib]	100.295	*[+cont, -sib]	100.295
IDENT-IO[cont]	100.295	IDENT-IO[cont]	100.295
*STOP	99.707	*STOP	99.705
		***STOPSTOP**	**99.535**

In addition to looking at the constraint ranking values for the two runs, I also compared the ability of one run's generated frequency to better match the input (attested) frequency throughout the tokens. The input frequencies were calculated by dividing the number of high ratings for each token in the experiment by the total of high ratings given to all variants of a given word. For example, for the root /gvh/ in Table 61, there were two inflections tested, with an expected and variant form for each one. For the expected/variant pair [gava]/[gaba], the expected form received 37 high ratings, and the variant form received 3. The input frequency was calculated by dividing each of the scores by their sum, resulting in 92.5% for the expected form and 7.5% for the variant. For the second inflection, the expected and variant forms each received 35 high ratings. This resulted in an input frequency of 50% for each of the forms.

In most cases, differences between the two generated frequencies were quite low, with an equal number of tokens obtaining a slightly more accurate generated frequency than the other (differences of 0.1% to 5%). There were, however, tokens for which the addition of *STOPSTOP in run 2 resulted in a generated frequency that was considerably closer to the input frequency. Both differences are demonstrated in Table 61 for the four tokens for the root /gvh/.

Table 61. Generated frequency comparison (gen. freq. 2 includes *STOPSTOP)

/gvh/	**# of High Ratings**	**Input Frequency**	**Generated Frequency 1**	**Generated Frequency 2**
gava	37	92.5%	**75.3%**	74.7%
gaba	3	7.5%	**24.7%**	25.3%
ligbot	35	50%	74.1%	**61.4%**
ligvot	35	50%	25.9%	**38.6%**

Neither run's generated frequency was able to mimic the input frequency exactly for the tokens [gava] and [gaba], with a difference of 17.2% and 17.8% between the input and the generated frequencies 1 and 2, respectively. The second set of tokens, [ligbot] and [ligvot], achieved a considerably better match in frequencies, with a 12.7% difference between the two generated frequencies and a difference of 12.1% between generated frequency 2 and the input frequency (as opposed to a difference of 24.8% in generated frequency 1). This is, of course, in great part due to the high acceptability of the variant [ligvot] with a post-consonantal fricative, which supports the addition of the constraint *STOPSTOP.

Lastly, I looked at the average difference between each of the generated frequencies and the input frequency to determine if one run's difference was significantly closer to the input frequency. A paired *t*-test revealed no significant difference, with a slightly lower average difference in the run containing *STOPSTOP ($t(52) = 1.258$,

$p > 0.05$), at 11.8% (the average for the first run was 12.1%). Since the presence of *StopStop does not seem to substantially affect the ranking values of the other constraints, I elected to keep this constraint, using run 2 for the final analysis of variation.

Looking at the generated frequencies across all tokens, while all but one of the input frequency/generated frequency pairings matched in their general patterns of preference,[24] there are many instances where the generated frequency is 15% higher or lower than the input frequency. The reason for this is the relatively wide range of input frequencies for a given condition. Given that all words in a given condition had similar preference patterns, the difference is likely not due to lexical effects, but rather the number of items used in each condition (and their respectively different levels of acceptance) and the high number of participants in the experiment. In Table 62, we see the difference in range between the input frequencies within each of the three contexts. In word-initial context, unaffected by *V-Stop or *StopStop, all tokens have the same generated frequency and constraint ranking probabilities. In post-vocalic context, the variant form [libdok] incurs a violation not only of *V-Stop, but also of *StopStop, resulting in a different generated frequency. In post-consonantal context, the token pair with a preceding stop ([ligbot] / [ligvot]) also requires a different ranking of *StopStop to account for the high acceptability rating of the variant form.

[24] By preference patterns, I checked to see that each of the forms' input frequency and generated frequency were on the same side of the midpoint on the 0.00-1.00 scale. The token pairings [linfoʃ] / [linpoʃ] had an input frequency of 0.58 / 0.42 and a generated frequency of 0.25 / 0.75 – a mismatch due to the fact that, unlike other tokens, the variant form [linpoʃ] received a higher acceptability rating than the expected form.

Table 62. Comparison of input and generated frequencies within context

Context	Token Pairs	Input Frequency	Generated Frequency
Word-initial *Expected: stop* *Variant: fricative*	[**b**adak] / [**v**adak]	0.90 / 0.10	0.75 / 0.25
	[**k**ibes] / [**χ**ibes]	0.61 / 0.39	
	[**p**irek] / [**f**irek]	0.88 / 0.12	
Post-vocalic *Expected: fricative* *Variant: stop*	[li**v**dok] / [li**b**dok]	0.65 / 0.35	0.77 / 0.23
	[ba**χ**a] / [ba**k**a]*	0.83 / 0.07	0.49 / 0.25
	[na**f**aʃ] / [na**p**aʃ]	0.81 / 0.19	0.75 / 0.25
Post-consonantal *Expected: stop* *Variant: fricative*	[lig**b**ot] / [lig**v**ot]	0.50 / 0.50	0.61 / 0.39
	[liv**k**ot] / [liv**χ**ot]*	0.61 / 0.02	0.51 / 0.25
	[lis**p**or] / [lis**f**or]	0.68 / 0.32	0.75 / 0.25

* Token pairing is extracted from a root containing two alternating segments – frequencies do not sum to 100% because there were other tokens for the root.

Sample tableaux for the analysis of variation in alternating segments are in Table 63. In the first two tableaux for the root /btl/, the expected form contains a word-initial stop in [bitel], which received an acceptability rating of 77.1%. In the grammar generated by the GLA, it occurs 74.7% of the time. Its variant, [vitel], occurs when the selection point for *STOP is higher than the selection point for *[+cont, -sib] on the constraint ranking scale, 25.3% of the time. In the second set of tableaux, the expected form contains a post-vocalic fricative in [mevatel], which received an acceptability rating of 72%. Its variant, [mebatel], occurs when the selection point for *[+cont, -sib] is higher than the selection point for *V-STOP, which occurs 25.3% of the time in the grammar generated by the GLA.

Table 63. Tableaux for variation in /btl/

1. [bitel] (expected, 77.1%) ~ [vitel] (variant, 25.9%)

*A. [bitel] = *[+cont, -sib] » *STOP (occurs 74.7% in grammar):*

/btl/ + 3p.sg.m.past *'cancelled'*	*V-STOP	*[+cont, -sib]	IDENT-IO[cont]	*STOP	*STOPSTOP
☞a. bitel				*	
b. vitel		*!	*		

*B. [vitel] = *STOP » *[+cont, -sib] (occurs 25.3% in grammar):*

/btl/ + 3p.sg.m.past *'cancelled'*	*V-STOP	*STOP	*[+cont, -sib]	IDENT-IO[cont]	*STOPSTOP
a. bitel		*!			
☞b. vitel			*	*	

2. [mevatel] (expected, 72%) ~ [mebatel] (variant, 28%)

*A. [mevatel] = *V-STOP » *[+cont, -sib] (occurs 74.7% in grammar)*

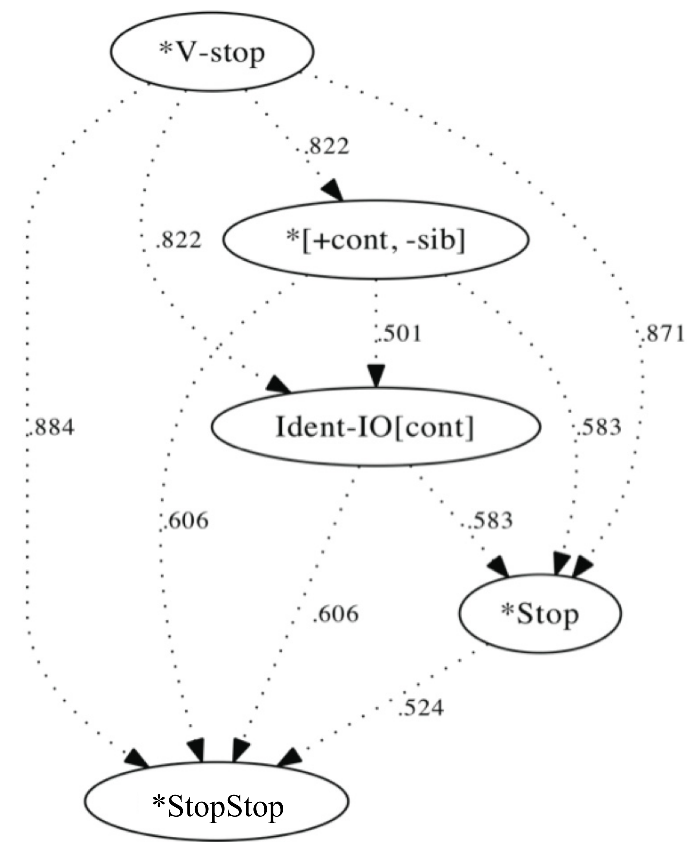
/btl/ + sg.m.pres. *'cancels'*	*V-STOP	*[+cont, -sib]	IDENT-IO[cont]	*STOP	*STOPSTOP
☞a. mevatel		*	*		
b. mebatel	*!			*	

*B. [mebatel] = *[+cont, -sib] » *V-STOP (occurs 25.3% in grammar)*

/btl/ + sg.m.pres. *'cancels'*	*[+cont, -sib]	*V-STOP	IDENT-IO[cont]	*STOP	*STOPSTOP
a. mevatel	*!		*		
☞b. mebatel		*		*	

The Hasse diagram in Figure 22 illustrates the probabilities for constraint interaction for the analysis of alternating segments. The numbers along the dotted arrows signify the probability that the higher constraint will dominate the lower constraint connected by the arrow for a given learning trial. While *V-STOP has the highest probability of dominating all other constraints, due to close ranking values, no two constraints are in strict domination relationship (with a value of 1) with each other. In fact, because of the assumption that the input of a given alternating segment is a stop, *[+cont, -sib], and IDENT-IO[cont] are violated by the same candidates, generating the same ranking value for them and assigning them to a 50% probability that one will dominate the other.

Figure 22. Hasse diagram for constraint rankings for alternating segments



Through the use of stochastic constraint rankings, we are able to account for the gradience found in the acceptability of variation in alternating segments in Modern Hebrew spirantization. Applying stochastic constraint rankings to words containing only alternating segments, the analysis was able to match the preference patterns of 49 of the

52 expected/variant pairs. All three mismatched expected/variant pairs contained the target segment in post-consonantal context. Two of the three followed a stop, for which the addition of *STOPSTOP to the analysis lessened the difference between the input and generated frequencies. This is seen in Table 64. In the case of the root /npʃ/, where the target segments [p] or [f] occur following a nasal, the addition of *STOPSTOP does not affect the ability of the algorithm to match the preference pattern.

Table 64. Mismatched frequencies for alternating segments

	Input Frequency	Output Frequency 1	Output Frequency 2 (with *STOPSTOP)
/gbh/			
ligvot	0.50	0.25	0.38
ligbot	0.49	0.74	0.61
/npʃ/			
linfoʃ	0.58	0.25	0.25
linpoʃ	0.41	0.74	0.74
/tps/			
litfos	0.52	0.25	0.38
litpos	0.47	0.74	0.61

There are still issues with the ability of the constraints used in this grammar to account for the variation in Modern Hebrew spirantization. Before proceeding to the combined model in Section 4.4.3, I discuss variable grammar (Adam 2002) as an alternative approach to variation.

4.3.2 Alternative Approach to Variation: Variable Grammar

Adam (2002) proposes an account of Modern Hebrew spirantization as an intermediate grammar in which alternation is variable. Although Adam considers variation to exist only in alternating segments (or paradigms), she postulates that this variation is a consequence of the existence of exceptionality. In this scenario, it is hypothesized that, as a result of language change, there is currently a crucial lack of ranking between the conflicting markedness and faithfulness constraints, which will eventually evolve into a ranking where the faithfulness constraints dominate the relevant markedness constraints, thus eliminating all alternation.

A summary of language change in Modern Hebrew spirantization, as it relates to the variable grammar approach, appears in Table 65. In the initial state of the grammar (older forms of Hebrew), the ranking of markedness over faithfulness resulted in alternating segments with no variation. In the current state of the grammar, variation is the result of markedness and faithfulness constraints for alternating segments being crucially unranked. The prediction this approach makes for the final state of the grammar is the demotion of markedness constraints, resulting in non-alternating paradigms without variation. Exceptional segments in all three states of the grammar are thought to have a ranking of faithfulness over markedness which remains fixed and does not exhibit variation.

Table 65. The process of change in Modern Hebrew grammar

Phase	Constraint Ranking	Segments	Variation
Initial *(Tiberian Hebrew)*	Fixed ranking: Markedness » Faithfulness	Alternating	No variation **b**ikeʃ / je**v**akeʃ
	Fixed ranking: Faithfulness » Markedness	Non-alternating (exceptional)	No variation **v**iter / je**v**ater
Reranking *(Modern Hebrew)*	**Crucial lack of ranking Markedness ~ Faithfulness**	**Alternating**	**Some variation** **b**ikeʃ ~ **v**ikeʃ / je**v**akeʃ
	Fixed ranking: Faithfulness » Markedness	Non-alternating (exceptional)	No variation: **v**iter (***b**iter) / je**v**ater
Final / Future	Fixed ranking: Faithfulness » Markedness	Non-alternating	No variation: **v**ikeʃ / je**v**akeʃ **v**iter / je**v**ater

In view of the data in Chapter 3, using unranked constraints to capture variation is problematic because very few expected ~ variant pairs exhibited equal levels of acceptance across speakers. Additionally, according to the data that is considered in Adam (2002), the dorsal alternating [k] exhibits variation in all three contexts but variation of the labials [p] and [b] is limited only to word-initial and post-consonantal contexts, where stops are expected. The study in Chapter 3 has yielded a more nuanced picture of the variation in Modern Hebrew spirantization. The description of variation from Adam (2002) is summarized in Table 66. The expected ~ variant pairs for alternating segments found acceptable in the experiment in Chapter 3 but not accounted for by the variable grammar analysis are underlined.

Table 66. Summary of variation in Adam (2002)

Context	**Past**	**Present / Infinitive**	**Gloss**
Word-initial and post-vocalic	**k**ibes ~ **χ**ibes **k**isa ~ **χ**isa	me**χ**abes ~ me**k**abes me**χ**ase ~ me**k**ase	‘to launder’ ‘to cover’
Word-initial	**p**iter ~ **f**iter **b**itel ~ **v**itel	me**f**ater *me**p**ater me**v**atel *me**b**atel	‘to fire’ ‘to cancel’
Post-consonantal	ka**f**a *ka**p**a la**v**aʃ *la**b**aʃ ra**χ**av *ra**k**av	lik**p**o ~ lik**f**o lil**b**oʃ ~ lil**v**oʃ lir**k**av ~ lir**χ**av	‘to freeze’ ‘to wear’ ‘to ride’

In the variable grammar approach, the lack of variation of the labials in post-vocalic position is an indication that spirantization in Modern Hebrew is currently undergoing change. It is postulated that the direction of the change is towards non-alternation. In Table 67, I have included the frequencies found in the experiment for each of the expected ~ variant pairs in Table 66. According to the results of the experiment, it appears that the acceptance of variants extends beyond the predictions of the variable grammar model. For instance, some labial stops received an acceptance frequency as high as 28% in post-vocalic position. In addition, for the root /btl/, the variant in word-initial context, [vitel], was rated less acceptable than the variant in post-vocalic position, [mebatel], which does not conform with the postulated free variation or the hypothesized trend of language change.

Table 67. Variation in the variable grammar approach with frequencies from the experiment [25]

Context		**Past**	**Present/Infinitive**	**Gloss**
Word-initial and post-vocalic	/**k**bs/	**k**ibes ~ **χ**ibes 0.61 0.39	me**χ**abes ~ me**k**abes 0.67 0.33	‘to launder’
	/**k**sh/	**k**isa ~ **χ**isa 0.77 0.23	me**χ**ase ~ me**k**ase 0.62 0.38	‘to cover’
Word-initial	/**p**tr/	**p**iter ~ **f**iter 0.90 0.10	me**f**ater ~ *me**p**ater 0.92 **0.07**	‘to fire’
	/**b**tl/	**b**itel ~ **v**itel 0.77 0.23	me**v**atel ~ *me**b**atel 0.72 **0.28**	‘to cancel’
Post-consonantal	/k**p**h/	ka**f**a ~ *ka**p**a 0.90 **0.10**	lik**p**o ~ lik**f**o 0.44 0.45	‘to freeze’
	/l**b**ʃ/	la**v**aʃ ~ *la**b**aʃ 0.78 **0.22**	lil**b**oʃ ~ lil**v**oʃ 0.63 0.37	‘to wear’
	/r**k**v/	ra**χ**av ~ *ra**k**av 0.84 **0.16**	lir**k**av ~ lir**χ**av 0.69 0.31	‘to ride’

The results of the experiment suggest that the direction of variation is not only alternation to non-alternation, as there is also some acceptability of variation in exceptionality. Rather than supporting a situation that trends in a single direction to non-alternation, the presence of alternating and non-alternating segments points to a system of acquisition where both affect each other – leading to mistakes during acquisition.

4.4 A Combined Model for Exceptionality and Variation

In previous sections, we saw the ability of an extension of set-indexation to account for exceptionality at the segmental level, and of Stochastic OT to account for probabilistic gradience in variation. In this section, I will demonstrate the inability of

[25] Bolded percentages are those which do not conform to the predictions of the variable grammar approach. All words here contain alternating segments.

either approach to account for both exceptionality and variation independently. I will then present the final analysis for Modern Hebrew spirantization using a combined model to account for the results from the experiment in Chapter 3.

4.4.1 Set-Indexation and Variation

In Section 4.2.1 I proposed an extension to Pater's (2000) set-based approach to allow for exceptionality at the segmental level. The main argument in favor of this move comes from hybrid words; alternation or exceptionality can not be determined at the word level because of the existence of words containing both types of segments. Set-indexation, however, is unable to adequately account for the variation described in the experiment in Chapter 3 without additional mechanisms. Namely, to obtain the gradience in variation, it is necessary to employ probabilistic re-ranking of the constraints, since there was a preference for one variant over another for most roots, rather than equal ratings of acceptability.

This is illustrated in Table 68 with an example of variation for the hybrid root /kph/. The expected form for the third person singular male past tense is [kafa], with a non-alternating [k] (which may be exceptional in some contexts) in word-initial context and an alternating [p] in post-vocalic context. In the experiment, this token received 90% of high ratings, while the variant form [kapa] received only 10%. The other two variants, [χafa] and [χapa], were not deemed acceptable by any participant as they did not receive any high ratings. If variation between the two acceptable forms ([kafa] and [kapa]) were at chance, one way to allow for variation would be a crucial lack of ranking between

*V-STOP and *[+cont, -sib]. The ranking of these two constraints below IDENT-IO[cont]$_1$ would prevent the two unattested forms ([χafa] and [χapa]) from surfacing, and would allow for a 50/50 chance that either of the acceptable forms would occur in the output at any given time. Based on the results of the experiment, however, the ranking of *V-STOP over *[+cont, -sib] would be favored over the opposite ranking most of the time, providing evidence for probabilistic ranking.

Table 68. [kafa] (expected, 90%) ~ [kapa] (variant, 10%)

/k$_1$ph/ + 3p.sg.m. *'froze'*	**IDENT-IO[cont]$_1$**	***V-STOP**	***[+cont, -sib]**	***STOP**	**IDENT-IO[cont]**
☞a. k$_1$afa (0.9)			*	*	*
☞b. k$_1$apa (0.1)		*		**	
c. χ$_1$afa	*!		**		**
d. χ$_1$apa	*!		*	*	*

I conclude that probabilistic constraint ranking is necessary in order to be able to better account for gradient differences in acceptability among tokens.

4.4.2 Stochastic OT and Exceptionality

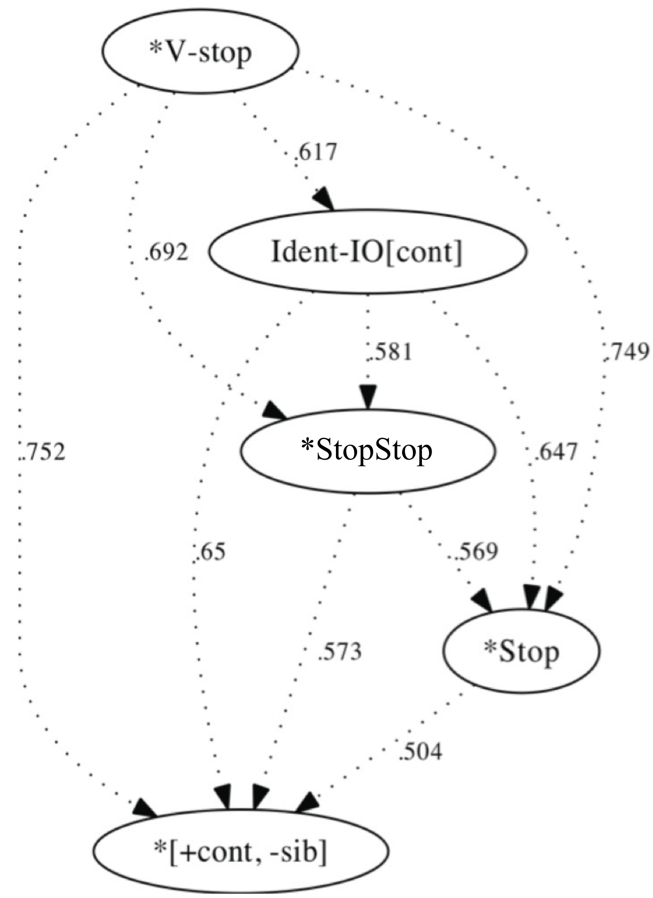
In Section 4.3.1, I discussed the capacity of the GLA and Stochastic OT to handle the gradience exhibited in the experiment – although it is not perfect in achieving exact matches between input and generated frequencies, it is able to account for gradience in variation for alternating segments. In this section, I consider the relative inadequacy of an analysis for Modern Hebrew spirantization using only Stochastic OT without set membership for exceptional segments. In order to create the analysis, I ran the data through the GLA (using OT Soft) using the same parameters as those described for the second run described in Section 4.3.1. For this run, however, I also included roots containing exceptional segments. Without the addition of set-membership and set-indexed constraints, exceptional segments incurred violations only of general constraints. Table 69 contains the constraint ranking values for this run. Here we see that the faithfulness constraint IDENT-IO[cont] is ranked a close second to the contextual markedness constraint *V-STOP. The rest of the ranking values seem similar to those generated for alternating segments in Table 60.

Table 69. Constraint ranking values (analysis without sets)

Constraint	Ranking Value
*V-STOP	101.91
IDENT-IO[cont]	**101.07**
*[+cont, -sib]	100.50
*STOPSTOP	100.01
*STOP	99.986

In the Hasse diagram in Figure 23 we see that the close ranking values for *V-STOP and IDENT-IO[cont] leads to the ranking of IDENT-IO[cont] over *V-STOP about 40% of the time. This, I assume, is due to the surfacing of exceptional stops in post-vocalic contexts. Also noteworthy is the fact that no constraint dominates any of the others more than 75% of the time, indicating a high level of overlap between the constraints.

Figure 23. Hasse diagram for constraints without sets



There are several problems that arise in the absence of set membership for exceptional segments. First and foremost, the high ranking of IDENT-IO[cont] and the subsequent overlap between IDENT-IO[cont] and *V-STOP lead to a higher frequency of alternating segments surfacing as stops in post-vocalic context than was evidenced in the experiment. This is seen in Table 70, where the variant [baka] received only 7% of high ratings in the experiment but is generated 40% of the time by the GLA. Additionally, the lack of set-indexed faithfulness results in a very high frequency of the surfacing of exceptional stops as fricatives in post-vocalic context, something that is very seldom considered acceptable. This is seen in the case of [meχajem], where the [χ] is derived from an exceptional stop. This token did not receive any high ratings in the experiment, yet the generated frequency for it is 59%. Lastly, we see that Stochastic OT is unable to account for hybrids. For the case of hybrid words such as [mevaker], where the expected form contains an alternating and exceptional segment in post-vocalic context (with high ratings 72% of the time), the GLA is unable to generate any token where there are both a stop and a fricative in the same context.

Table 70. Problems for different roots with absence of sets

	Target	**Input Frequency**	**Generated Frequency**
Alternating	[ba**k**a]	0.07	0.40
Exceptional	[me**χ**ajem]	0.00	0.59
Hybrid	[meva**k**er]	0.72	0.00

A closer look at hybrid roots reveals that the algorithm has special difficulty with hybrids containing both target segments in post-vocalic context. There are no rankings under which the algorithm can generate a post-vocalic stop and a post-vocalic fricative simultaneously. This means that, for the root /bkʃ/ in Table 71, the candidate with the highest percentage of high ratings (candidate (a), [mevakeʃ], 57% input frequency) is never generated by the algorithm. Additionally, the candidate with the highest generated frequency (candidate (c), [mevaχeʃ], 59% generated frequency) received no high ratings in the experiment at all. The only candidate whose input and generated frequencies matched was candidate (b), [mebakeʃ], in which both target segments are stops. This candidate occurs in the output when, due to the high overlap between the two highest constraints, the selection point for IDENT-IO[cont] is higher than the selection point for *[+cont, -sib], since both segments are specified as [-cont] in the input. Additionally, candidate (d), with a 3.3% acceptability rating (higher than candidate (c)) is not generated by the algorithm.

Table 71. Hybrid root - input/generated frequency mismatch

/**bk₁**ʃ/ + sg.m.pres *'asks for'*	***V-STOP** (.617)	**IDENT-IO[cont]** (.581)	***STOPSTOP** (.569)	***STOP** (.504)	***[+cont, -sib]**
a. me**vak₁**eʃ *Input (57.4%)* *Generated **(0%)***	*	*		*	*
b. me**bak₁**eʃ *Input (39.3%)* *Generated **(40.5%)***	**			**	
☞c. me**vaχ₁**eʃ *Input (0%)* *Generated **(59.5%)***		**			**
d. me**baχ₁**eʃ *Input (3.3%)* *Generated **(0%)***	*	*		*	*

Using only one faithfulness constraint leads to considerable overlap between IDENT-IO[cont] and *V-STOP, which in turn leads to the high generated frequency of words such as candidate (c) in Table 71, which were never judged acceptable in the experiment.

In addition to the issues with the lack of set membership and set-indexed constraints outlined above, there was a specific issue having to do with two roots used in the experiment. The hybrid root /kpʔ/ 'to freeze' and the /kph/ 'to force' with two alternating segments both contain a [k] in root-initial position and a [p] in root-medial position. While the [p] in both is alternating, the [k] in the first root is exceptional and alternating in the second root. With the inability to distinguish between the two [k] sounds, the algorithm arrives at the same generated frequencies for comparable output forms of both roots. This is seen in Table 72 with the bolded cells representing a mismatch between the input and generated frequencies greater than 0.15.

Table 72. /kfʔ/ and /kfh/ - same generated frequencies for hybrid and root containing two alternating segments

Target (hybrid root)	Input Frequency	Target (2 alternating)	Input Frequency	Generated Frequency
[likfo]	**0.452**	[likfot]	**0.194**	0.000
[likpo]	0.435	[likpot]	**0.104**	0.339
[liχfo]	**0.048**	[liχfot]	0.194	0.257
[liχpo]	**0.065**	[liχpot]	0.507	0.404

Having an identical generated frequency for these two roots is problematic in at least half of the tokens. In the hybrid root, the token with the highest input frequency ([likfo], 45%) is never generated by the algorithm. Additionally, the two tokens with the lowest input frequencies ([liχfo], 4.8% and [liχpo], 6.5%) have relatively high generated frequencies (25.7% and 40.4%, respectively). In the root containing two alternating segments, a token with a relatively high input frequency ([likfot], 19.4%) is never generated by the algorithm. Additionally, the token with the lowest input frequency ([likpot], 10.4%) is generated by the algorithm three times more. Therefore stochastic constraint ranking without indexation fails to capture the difference between alternating and exceptional target segments in phonologically similar words.

Having seen where set-indexation fails to account for variation, and Stochastic OT fails to account for exceptionality, the next section describes the final analysis combining the two to account for alternation, exceptionality, and variation simultaneously.

4.4.3 The Combined Model

To account for alternation, exceptionality, and gradient variation in Modern Hebrew Spirantization, I propose an OT analysis combining the indexation of exceptional segments to a set with a corresponding faithfulness constraint and stochastic constraint ranking. This section describes the combined model and the ways in which it improves on its two components used in isolation.

The data presented to the GLA in OT Soft consisted of all tokens used in the experiment in Chapter 3. As described in Section 4.3.1, within each root, the input frequency for each token was calculated by dividing the number of high ratings received by the total of high ratings received for all variants of that token. In addition to the data used in earlier runs using OT Soft, violations of IDENT-IO[cont]$_1$ were also included. In Table 73 we see the constraint ranking values for the combined model and those for stochastic constraint ranking without set-indexed constraints. One noticeable difference between these ranking values is that the presence of IDENT-IO[cont]$_1$ results in the ranking of the general faithfulness constraint below the markedness constraints involved.

This is because IDENT-IO[cont]$_1$ is able to account for exceptional segments, which do not adhere as consistently to the distribution of Modern Hebrew spirantization. Additionally, since the input for exceptional fricatives is assumed to be a fricative (not a stop, as is the assumption for alternating segments), violations incurred by exceptional fricatives result in more violations of IDENT-IO[cont] than [+cont, -sib]. The ranking values of the markedness constraints are similar to those generated by the GLA without set-indexation. Namely, there is a large amount of overlap between the different markedness constraints, accounting for much of the variation found in the experiment.

Table 73. Constraint ranking values comparison

Constraint	**Ranking Value (Combined Model)**	**Ranking Value (Without Set-indexation)**
IDENT-IO[cont]$_1$	103.79	
*V-STOP	102.13	101.91
*[+cont, -sib]	101.14	100.50
*STOPSTOP	100.48	100.01
*STOP	98.86	99.986
IDENT-IO[cont]	-1,797.54	**101.07**

Table 74 demonstrates the improvements in the percentage of generated frequency for the three target words in Table 70. Recall that, when generated without set-indexation, the input and generated frequencies for [baka], [meχajem], and [mevaker] were problematically mismatched for different reasons. The variant word [baka], with an alternating stop in post-vocalic context, was only attested in the experiment 7% of the time, whereas it was generated 40% of the time by the GLA without set-indexation. Once set-indexation was introduced, there was an improvement with a lowering of the generated frequency to 34%. The variant word [meχajem], with an exceptional [k] surfacing as a fricative in post-vocalic context, was not accepted by any of the participants in the experiment, yet the GLA without set-indexation generated this token 59% of the time. While set-indexation was still unable to eliminated this token from ever being generated, the generated frequency dropped to 24% once it was introduced, matching its preference pattern. Finally, the expected hybrid word [mevaker], which was rated as acceptable 72% of the time was never generated by the GLA without set-indexation. With set-indexation, the generated frequency rose to 42%, matching its preference pattern.

Table 74. Improvement for problematic forms for different root types with sets

	Target	**Input Frequency**	**Generated Frequency (no sets)**	**Generated Frequency (with sets)**
Alternating	[baka]	0.07	0.40	**0.34**
Exceptional	[meχajem]	0.00	0.59	**0.24**
Hybrid	[mevaker]	0.72	0.00	**0.42**

While the generated frequencies using the GLA with set-indexation do not mimic the input frequency exactly, there is an improvement in using set-indexation. It is especially important that words which were rated as highly acceptable in the experiment, such as [mevaker] are accounted for in the generated frequency. That is, unlike the GLA model without set-indexation, the combined model does not exclude these forms, even though the generated frequency may be lower than the input frequency. The tableau in Table 75 shows the different tokens for the third person singular masculine form for the hybrid root /bkʃ/ 'to ask for'. One of the main improvements between this tableau and the one in Table 71 is the ability of the GLA with set-indexation to account for the token which was rated most acceptable in the experiment (candidate (a)) which the GLA with no set-indexation was not able to generate, with an input frequency of 57% and a generated frequency of 42% with set-indexation, matching its preference pattern. Additionally, candidate (c), which was not rated as acceptable by any of the subjects but was generated 59% of the time by the GLA with no set-indexation, is generated in significantly lower frequency with set-indexation, with a better match in its preference pattern.

Table 75. Hybrid root /bkʃ/ using the combined model

/**b**$\mathbf{k_1}$ʃ/ + sg.m.pres *'asks for'*	**IDENT-IO[cont]**$_1$ (.723)	***V-STOP** (.637)	***[+cont, -sib]** (.592)	***StopStop** (.717)	***STOP** (1)	**IDENT-IO[cont]**
☞a. me**v**a$\mathbf{k_1}$eʃ *Input (57.4%)* *Generated **(42.3%)***		*	*		*	*
b. me**b**a$\mathbf{k_1}$eʃ *Input (39.3%)* *Generated **(33.8%)***		**!			**	
c. me**v**a$\mathbf{\chi_1}$eʃ *Input (0%)* *Generated **(23.9%)***	*!		**			**
d. me**b**a$\mathbf{\chi_1}$eʃ *Input (3.3%)* *Generated **(0%)***	*!	*	*		*	*

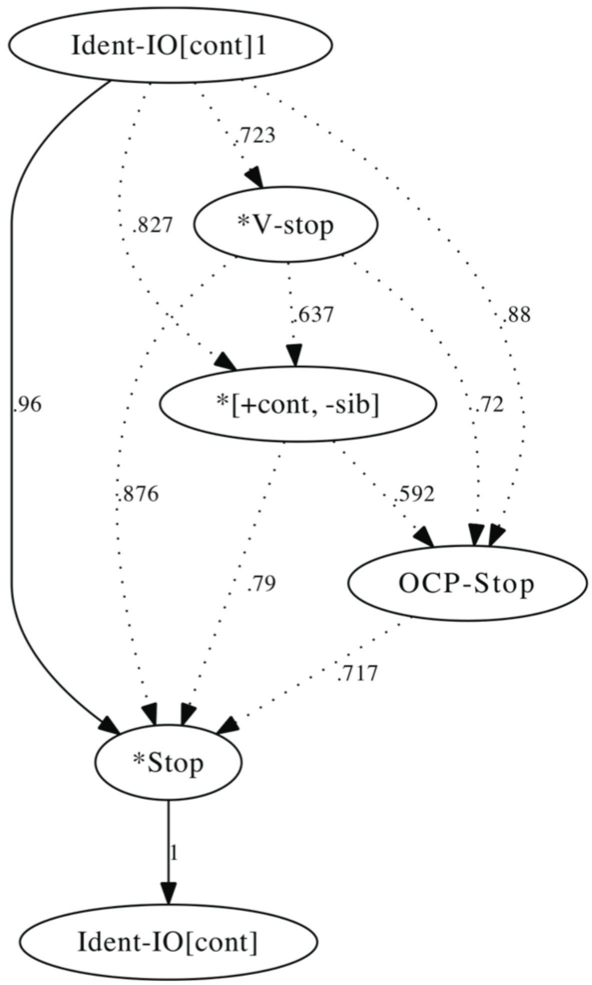
Finally, looking at the two roots from Table 72, we see the combined model's ability to generate different frequencies for the hybrid root /kpʔ/ and the root /kph/ with two alternating segments. In Table 76, we see that the generated frequency for the two roots is no longer the same. Moreover, with the exception of [likfot] and [likpot], the input frequency and generated frequency are near matches. The bolded cells represent the two target words for which there is a mismatch between the input and generated frequencies greater than 0.15. Comparing the mismatches from the combined model (in Table 76 with those which were generated without set-indexation in Table 72, the combined model is able to closely account for six of the eight target words whereas stochastic OT was only able to closely account for three of the eight target words without set-indexation.

Table 76. /kfʔ/ and /kfh/ - different generated frequencies for hybrid root and root containing two alternating segments

Hybrid /kfʔ/ - 'to freeze'			**Two Alternating Segments** /kfh/ - 'to force'		
Target	**Input Frequency**	**Generated Frequency**	**Target**	**Input Frequency**	**Generated Frequency**
[likfo]	0.452	0.328	[liχpot]	0.507	0.404
[likpo]	0.435	0.428	**[likpot]**	**0.104**	**0.339**
[liχfo]	0.048	0.068	[liχfot]	0.194	0.257
[liχpo]	0.065	0.176	**[likfot]**	**0.194**	**0.000**

The Hasse diagram in Figure 24 illustrates constraint rankings in the combined model. The set-indexed faithfulness constraint IDENT-IO[cont]$_1$ dominates the others, but is only in strict domination relation with *STOP and the general faithfulness constraint IDENT-IO[cont], which is the only constraint not stochastically ranked. The markedness constraint that overlaps most in its distribution with IDENT-IO[cont]$_1$ is *V-STOP, which allows exceptional stops to occur in the output as a fricative in post-vocalic context.

Figure 24. Hasse diagram for constraints in combined model



The combined model described in this section is a step towards an analysis of a phenomenon in which there is alternation, exceptionality, and variation. One of the drawbacks of this approach is the apparently static nature of exceptional indexation when entered into the GLA. Using the combined model, indexation of exceptional segments must have already taken place before stochastic constraint rankings can take place. This means that the learner is already presented with a distinction between exceptional and alternating segments, and she need not rely on statistical differences in the acceptability of their variation in order to distinguish between the two. The ability to combine the set-indexation mechanism with stochastic constraint rankings, rather than having to assume one before the other is calculated is an area for further development.

The following section describes partial constraint rankings (Anttila 1997, Anttila & Cho 1998, 2002) as an alternative to account for gradience in variation. I have chosen to use Stochastic OT to account for gradience because of its close link to the Gradual Learning Algorithm and its implementation in OT Soft. I have not tested partial constraint ordering with respect to these phenomena. Comparing performance of stochastic OT and partial constraint ordering with respect to the data presented here would be valuable in future research.

4.4.4 T-Orders and Partial Constraint Rankings

In partial constraint ordering (Anttila 1997, Anttila & Cho 1998, 2002) variation is obtained by the total rankings that a grammar (a set of ordered pairs of constraints) produces. By restricting constraint interaction to either strict domination or lack of crucial ranking, multiple grammars arise by means of a T-order, or a set of implicational universals that hold among the input/output pairs of a grammar based on the constraints in that grammar. Additionally, preferences for one variant over another are generated by calculating the frequency at which the variant emerges in the output generated by the multiple grammars.

Consider a hypothetical grammar containing three constraints (C_1, C_2, and C_3). In Table 77, we see the most restrictive possibility for these constraints with three ordered pairs. If all constraints are ranked with respect to one another, then we have no variation, with only one total ranking and one possible output.

Table 77. Grammar with one ordered pair

Ordered pairs	Total rankings	Output
C_1 » C_2 C_1 » C_3 C_2 » C_3	C_1 » C_2» C_3	$output_1$

In Table 78, we have two ordered pairs. By not ranking C_2 and C_3 with respect to one another, we are able to obtain two total rankings, allowing for variation in the output:

Table 78. Grammar with two ordered pairs

Ordered pairs	Total rankings	Output
C_1 » C_2	C_1 » C_2» C_3	$output_1$
C_1 » C_3	C_1» C_3 » C_2	$output_2$

In Table 79, only one ordered pair is specified. Like the grammar in Table 78, this grammar allows for variation in the output. However, in addition to predicting variation, this grammar also predicts a preference for $output_2$ over $output_1$, since it surfaces as a result of two distinct total rankings.

Table 79. Grammar with three ordered pairs

Ordered pair	Total rankings	Output
$C_1 \gg C_2$	$C_1 \gg C_2 \gg C_3$	$output_1$
	$C_1 \gg C_3 \gg C_2$	$output_2$
	$C_3 \gg C_1 \gg C_2$	$output_2$

In addition to restricting the number of ordered pairs a grammar has, there is also the possibility of not having any ordered pairs at all. In the hypothetical grammar, this would result in six total rankings. This is illustrated in Table 80.

Table 80. Grammar with no ordered pairs

Ordered pair	Total rankings	Output
Ø	$C_1 \gg C_2 \gg C_3$	$output_1$
	$C_1 \gg C_3 \gg C_2$	$output_2$
	$C_3 \gg C_1 \gg C_2$	$output_2$
	$C_3 \gg C_2 \gg C_1$	$output_2$
	$C_2 \gg C_1 \gg C_3$	$output_1$
	$C_2 \gg C_3 \gg C_1$	$output_2$

When using partial constraint ordering, speakers' preferences for one variant over another become more fine tuned with the addition of constraints, and an increase in the number of possible total rankings. The resulting T-Order shows entailment relationships between each input/output pair and others in the grammar. There are two calculations computed by T-Order Generator (Anttila & Andrus 2006) – precision and recall. Precision shows how many of the implicational universals generated using the constraints of the grammar conflict with the quantitative ordering (entailment relationships) in the data. Recall shows how many of the quantitative orderings in the data are actually captured by the implicational universals. Entailment relationships are depicted in a T-Order in the form of one input/output pair's frequency in the grammar predicting another input/output pair's frequency. Looking at the calculations and entailment relationships produced by the T-Order Generator, we are able to look for systematicity in mismatched entailment relationships to provide evidence for the addition of new constraints to the grammar.

One way to improve the results achieved by the GLA in matching input and generated frequencies involves calculating the T-Orders (Anttila & Andrus 2006) for the constraints proposed with the frequency of each of the tokens. These calculations include the precision (how many implicational universals conflict with the quantitative ordering) and recall (how many of the quantitative orderings in the data are captured by the implicational universals). Calculating these for the grammar generated by the combined model, the percision is 75.6% and the recall is 33.7%. One of the ways in which T-Orders are useful to constructing grammars is the information they provide about mismatches in entailment relationship. Of the 8,479 entailment relationships generated for the grammar in the combined model, about 2,000 were a mismatch with the frequency of the tokens in the data. A closer look at the mismatched entailments will aid in improving the performance of the GLA in matching the input and generated frequencies for the tokens with the addition of new constraints in the grammar.

4.5 Accounting for the Experiment Results

In this section, I review the results from the experiment and demonstrate the ability of the combined model discussed in this chapter to account for the acceptability of variation in alternating and exceptional segments. Additionally, I raise some areas that require further attention in future research.

4.5.1 Alternating Segments

Let us first look at the ability of the combined model to handle the variation seen in alternating segments. As predicted in Hypotheses 1a and 1b, the results showed that variation is acceptable in these segments. Recall that participants favored the expected forms (fricatives in post-vocalic context and stops elsewhere) over the variant forms. This preference for the expected form is borne out in the combined model for 45 of the 46 expected/variant pairs used in the experiment. Additionally, the addition of *STOPSTOP ensured that the high acceptability of a variant in post-consonantal context (a fricative) is accounted for in the analysis, as predicted by the significant interaction of position and consonant type. The word listed in Table 81 show the ability of the combined model to match the preference pattern for words containing alternating segments only.

Table 81. Preference pattern matches for alternating segments

/bdk/	Input Fr.	Gen Fr.	/ktv/	Input Fr.	Gen Fr.	/rkv/	Input Fr.	Gen Fr.
badak	0.900	0.788	liχtov	0.667	0.722	raχav	0.837	0.662
vadak	0.100	0.212	liktov	0.333	0.279	rakav	0.163	0.338
/bdk/	Input Fr.	Gen Fr.	/lbʃ/	Input Fr.	Gen Fr.	/sbl/	Input Fr.	Gen Fr.
livdok	0.642	0.722	lavaʃ	0.783	0.662	lisbol	0.706	0.788
libdok	0.358	0.279	labaʃ	0.217	0.338	lisvol	0.294	0.212
/bnh/	Input Fr.	Gen Fr.	/lbʃ/	Input Fr.	Gen Fr	/sbl/	Input Fr.	Gen Fr.
bana	0.783	0.788	lilboʃ	0.630	0.788	saval	0.632	0.662
vana	0.217	0.212	lilvoʃ	0.370	0.212	sabal	0.368	0.338
/bnh/	Input Fr.	Gen Fr.	/mkr/	Input Fr.	Gen Fr.	/ʃbr/	Input Fr.	Gen Fr.
livnot	0.649	0.662	maχar	0.973	0.662	ʃavar	0.655	0.662
libnot	0.351	0.338	makar	0.027	0.338	ʃabar	0.345	0.338
/brr/	Input Fr.	Gen Fr.	/mkr/	Input Fr.	Gen Fr.	/ʃbr/	Input Fr.	Gen Fr.
birer	0.854	0.788	limkor	0.712	0.788	liʃbor	0.632	0.788
virer	0.146	0.212	limχor	0.288	0.212	liʃvor	0.368	0.212
/brr/	Input Fr.	Gen Fr.	/npʃ/	Input Fr.	Gen Fr.	/ʃkv/	Input Fr.	Gen Fr.
mevarer	0.818	0.662	nafaʃ	0.814	0.662	ʃaxav	0.949	0.662
mebarer	0.182	0.338	napaʃ	0.186	0.338	ʃakav	0.051	0.338
/btl/	Input Fr.	Gen Fr.	/pgʃ/	Input Fr.	Gen Fr.	/ʃkv/	Input Fr.	Gen Fr.
bitel	0.771	0.788	pagaʃ	0.947	0.788	liʃkav	0.900	0.788
vitel	0.229	0.212	fagaʃ	0.053	0.212	liʃxav	0.100	0.212
/btl/	Input Fr.	Gen Fr.	/pgʃ/	Input Fr.	Gen Fr.	/spr/	Input Fr.	Gen Fr.
mevatel	0.720	0.662	lifgoʃ	0.571	0.722	safar	0.854	0.662
mebatel	0.280	0.338	lipgoʃ	0.429	0.279	sapar	0.146	0.338
/gbh/	Input Fr.	Gen Fr.	/prk/	Input Fr.	Gen Fr.	/spr/	Input Fr.	Gen Fr.
gava	0.925	0.662	pirek	0.875	0.788	lispor	0.681	0.788
gaba	0.075	0.338	firek	0.125	0.212	lisfor	0.319	0.212
/gbh/	Input Fr.	Gen Fr.	/prk/	Input Fr.	Gen Fr.	/ʃpx/	Input Fr.	Gen Fr.
ligvot	0.507	0.466	mefarek	0.857	0.662	liʃpoχ	0.740	0.788
ligbot	0.493	0.534	meparek	0.143	0.338	liʃfoχ	0.260	0.212
/kʔs/	Input Fr.	Gen Fr.	/ptr/	Input Fr.	Gen Fr.	/ʃpχ/	Input Fr.	Gen Fr.
kaas	1.000	0.788	piter	0.902	0.788	ʃafaχ	0.778	0.662
χaas	0.000	0.212	fiter	0.098	0.212	ʃapaχ	0.222	0.338
/kʔs/	Input Fr.	Gen Fr.	/ptr/	Input Fr.	Gen Fr.	/tps/	Input Fr.	Gen Fr.
liχos	0.708	0.662	mefater	0.923	0.662	tafas	0.881	0.662
likos	0.292	0.338	mepater	0.077	0.338	tapas	0.119	0.338
/ksh/	Input Fr.	Gen Fr.	/ptχ/	Input Fr.	Gen Fr.	/tps/	Input Fr.	Gen Fr.
kisa	0.773	0.788	pataχ	0.875	0.788	litfos	0.524	0.466
χisa	0.227	0.212	fataχ	0.125	0.212	litpos	0.476	0.534
/ksh/	Input Fr.	Gen Fr.	/ptχ/	Input Fr.	Gen Fr.	/zkh/	Input Fr.	Gen Fr.
meχase	0.623	0.662	liftoaχ	0.783	0.722	zaχa	0.972	0.662
mekase	0.377	0.338	liptoaχ	0.217	0.279	zaka	0.028	0.338
/ktv/	Input Fr.	Gen Fr.	/rkv/	Input Fr.	Gen Fr.	/zkh/	Input Fr.	Gen Fr.
katav	0.972	0.788	lirkav	0.694	0.788	lizkot	0.833	0.788
χatav	0.028	0.212	lirχav	0.306	0.212	lizχot	0.167	0.212

The one word containing alternating segments for which there was a mismatch in the preference pattern is a form of the root /npʃ/. In the case of [linpoʃ] (expected) and [linfoʃ] (variant), the variant form received 58% of the high ratings, whereas the expected form received only 41% of the high ratings. This was unusual with resepect to the general trend for alternating segments where the expected form (i.e. the one conforming with the spirantization) received a higher percent of high ratings. In Table 82 we see that the generated frequency for the less preferred, expected form [linpoʃ], is much higher than the acceptability rating it received in the experiment.

Table 82. Mismatched input and generated frequency for alternating segments

/nps/	Input frequency	Generated frequency
[linfoʃ]	0.585	0.212
[linpoʃ]	0.415	0.788

4.5.2 Exceptional Segments

Looking at exceptional segments, the results showed that some variation was acceptable in these segments but that it was less acceptable than the variation of alternating segments. Here again, the expected forms were preferred by participants in the experiment. The combined model was able to closely match this preference in 30 of 32 words containing an exceptional segment as the only target segment in the word. The word listed in Table 83 show the ability of the combined model to match the preference pattern for words containing exceptional segments only.

Table 83. Preference pattern matches for exceptional segments

/bχn/	Input Fr.	Gen Fr.	/kbs/	Input Fr.	Gen Fr.	/tvh/	Input Fr.	Gen Fr.
baχan	0.949	0.881	kibes	0.614	0.788	tava	0.744	0.881
bakan	0.051	0.119	χibes	0.386	0.212	taba	0.256	0.119
/bχn/	Input Fr.	Gen Fr.	/kbs/	Input Fr.	Gen Fr.	/tvh/	Input Fr.	Gen Fr.
livχon	0.947	0.835	meχabes	0.673	0.662	litvot	0.750	0.854
livkon	0.053	0.165	mekabes	0.327	0.338	litbot	0.250	0.146
/dχh/	Input Fr.	Gen Fr.	/kjm/	Input Fr.	Gen Fr.	/vdh/	Input Fr.	Gen Fr.
daχah	0.972	0.881	kijem	0.860	0.976	vida	0.861	0.835
dakah	0.028	0.119	χijem	0.140	0.024	bida	0.139	0.165
/dχh/	Input Fr.	Gen Fr.	/kjm/	Input Fr.	Gen Fr.	/vdh/	Input Fr.	Gen Fr.
lidχot	0.875	0.854	mekajem	1.000	0.761	mevade	0.729	0.881
lidkot	0.125	0.146	meχajem	0.000	0.239	mebade	0.271	0.119
/dkr/	Input Fr.	Gen Fr.	/krʔ/	Input Fr.	Gen Fr.	/vtr/	Input Fr.	Gen Fr.
dakar	0.946	0.761	kara	0.973	0.976	viter	0.947	0.835
daχar	0.054	0.239	χara	0.027	0.024	biter	0.053	0.165
/dkr/	Input Fr.	Gen Fr.	/krʔ/	Input Fr.	Gen Fr.	/vtr/	Input Fr.	Gen Fr.
lidkor	0.919	0.898	likro	0.972	0.761	mevater	0.778	0.881
lidχor	0.081	0.102	liχro	0.028	0.239	mebater	0.222	0.119
/fdχ/	Input Fr.	Gen Fr.	/lvh/	Input Fr.	Gen Fr.	/χjh/	Input Fr.	Gen Fr.
fideaχ	0.784	0.835	lava	0.783	0.881	liχjot	0.972	0.881
pideaχ	0.216	0.165	laba	0.217	0.119	likjot	0.028	0.119
/fdχ/	Input Fr.	Gen Fr.	/lvh/	Input Fr.	Gen Fr.	/χjχ/	Input Fr.	Gen Fr.
mefadeaχ	0.833	0.881	lilvot	0.868	0.835	χijeχ	0.971	0.835
mepadeaχ	0.167	0.119	lilbot	0.132	0.165	kijeχ	0.029	0.165
/fʃl/	Input Fr.	Gen Fr.	/ʃkʔ/	Input Fr.	Gen Fr.	/χjχ/	Input Fr.	Gen Fr.
fiʃel	0.837	0.835	liʃkoa	0.755	0.976	meχajeχ	0.921	0.881
piʃel	0.163	0.165	liʃχoa	0.245	0.024	mekajeχ	0.079	0.119
/fʃl/	Input Fr.	Gen Fr	/ʃkʔ/	Input Fr.	Gen Fr.	/χzr/	Input Fr.	Gen Fr.
mefaʃel	0.762	0.881	ʃaka	0.947	0.761	χazar	0.947	0.835
mepaʃel	0.238	0.119	ʃaχa	0.053	0.239	kazar	0.053	0.165

The one root containing alternating segments for which there was a mismatch in the preference pattern is /tlfn/. Recall that participants showed acceptability of near free variation for both conjugations of the root. For this reason, this root showed the highest difference between the input and generated frequencies in the analysis. In Table 84, we see that the generated frequency for the variant forms [tilpen] and [metalpen], is much lower than the acceptability rating it received in the experiment.

Table 84. Mismatched input and generated frequency for alternating segments

/tlfn/	Input frequency	Generated frequency
[tilfen]	0.535	0.835
[tilpen]	0.465	0.165
[metalfen]	0.513	0.835
[metalpen]	0.487	0.165

4.5.3 Words with Two Target Segments

Words containing two target segments posed a more difficult task for the analysis. For each word, there were four stimuli; the expected form and three variant forms. Recall that, contrary to hypothesis 3c, participants rated variants of exceptional segments less acceptable when they occurred in hybrid words than when they were the only target segments in a word. Since the analysis treated segments similarly whether they were the only target segments in a word or were in hybrid words, there were several instances where a form that did not receive any high ratings in the experiment was generated by the analysis, or vice versa.

In most words containing two target segments, participants showed a preference for the expected form for each word. The combined model was able to match the preference pattern for the two most acceptable tokens for 11 of the 12 words used. The words listed in Table 85 show the ability of the combined model to match the preference pattern for the two highest rated forms of words containing two target segments.

Table 85. Preference pattern matches for words containing two target segments

/bkh/	Input Fr.	Gen Fr.	/bkʃ/	Input Fr.	Gen Fr.	/kph/	Input Fr.	Gen Fr.
baχa	0.833	0.450	bikeʃ	0.685	0.617	kafa	0.649	0.450
baka	0.071	0.338	biχeʃ	0.037	0.171	kapa	0.123	0.338
vaka	0.048	0.000	vikeʃ	0.241	0.144	χafa	0.053	0.212
vaχa	0.048	0.212	viχeʃ	0.037	0.068	χapa	0.175	0.000
/bkh/	Input Fr.	Gen Fr.	/bkS/	Input Fr.	Gen Fr.	/kph/	Input Fr.	Gen Fr.
livkot	0.614	0.509	mevakeʃ	0.574	0.423	liχpot	0.507	0.509
libkot	0.333	0.279	mebakeʃ	0.393	0.338	likfot	0.194	0.000
libχot	0.035	0.000	mebaχeʃ	0.033	0.000	likpot	0.104	0.279
livχot	0.018	0.212	mevaχeʃ	0.000	0.239	liχfot	0.194	0.212
/bkr/	Input Fr.	Gen Fr.	/bχr/	Input Fr.	Gen Fr.	/kph1/	Input Fr.	Gen Fr.
biker	0.783	0.617	baχar	0.685	0.669	kafa1	0.897	0.637
biχer	0.022	0.171	bakar	0.056	0.119	kapa1	0.103	0.338
viker	0.196	0.144	vakar	0.019	0.000	χafa1	0.000	0.024
viχer	0.000	0.068	vaχar	0.241	0.212	χapa1	0.000	0.000
/bkr/	Input Fr.	Gen Fr.	/bχr/	Input Fr.	Gen Fr.			
mevaker	0.723	0.423	livχor	0.673	0.615			
mebaker	0.255	0.338	libkor	0.073	0.110			
mebaχer	0.021	0.000	libχor	0.236	0.225			
mevaχer	0.000	0.239	livkor	0.018	0.051			

The one word containing two target segments for which there was a mismatch in the preference pattern of the two highest rated forms is a conjugation of /kfh/. In the experiment, the variant [likfo] had a slightly higher acceptability rating than the expected form [likpo]. In Table 86, we see that the frequency generated in the analysis, however, shows preference for the expected form [likpo].

Table 86. Mismatched input and generated frequency for hybrid word

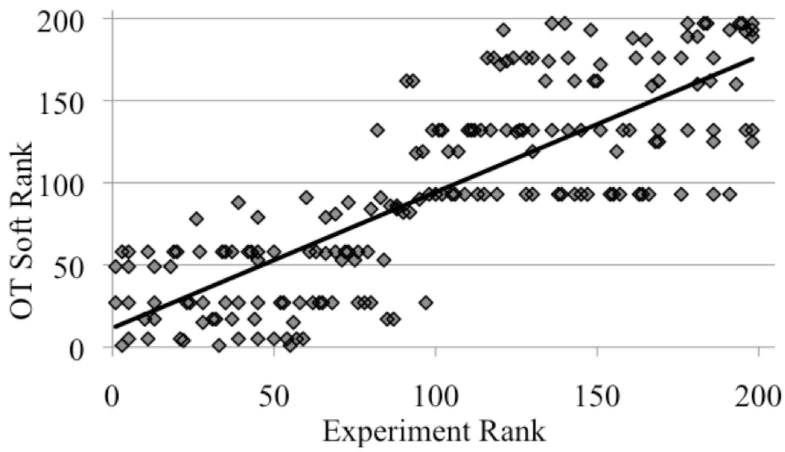
/kph/	Input frequency	Generated frequency
[likfo]	0.452	0.328
[likpo]	0.435	0.428
[liχfo]	0.048	0.068
[liχpo]	0.065	0.176

4.5.4 Matching the Experiment Results and OT Soft Simulation

As illustrated in the previous sections, the combined model was able to match the preference patterns for most of the results in the experiment. The forms for which the input and generated frequencies did not match, [linpoʃ]/[linfoʃ], [tilpen]/[tilfen], and [likpo]/[likfo], point to the possibility a higher rate of acceptability of variant forms for words containing the voiceless labials [p] and [f] in post-consonantal context – a pattern not seen with other segments. Additionally, in words containing two target segments, although the combined model was capable of matching the preferred pattern for the two highest ranked forms of each words, it also generated forms that did not receive any high ratings, as well as failed to generate some variants which received some high ratings in the experiment. These two issues need to be further examined to determine whether the addition of constraints or other mechanism can resolve them.

A Spearman's Rank correlation test comparing the probabilities from the experiment results for all tokens with the corresponding probabilities from the OT Soft simulation was highly significant ($\rho(202) = 0.821$, $p < .001$). This suggests that, overall, the simulation successfully modeled the preference pattern found in the experiment. The correlation between the ranks of the probabilities is shown in Figure 25.

Figure 25. Correlation between experiment results and OT Soft simulation



4.6 Chapter Summary

In this chapter, I have provided an OT analysis of the results of the experiment described in Chapter 3 which indicate that acceptability of variation is gradient in Modern Hebrew spirantization, and that variation is more acceptable in alternating segments than in exceptional ones. To account for these results, I proposed a combined model extending set-indexation (Pater 2000) to account for exceptionality at the segmental level and using Stochastic OT (Boersma 1998, Hayes & MacEachern 1998, Zuraw 2000, Boersma & Hayes 2001) to account for variation. The ability of the combined model to match preference patterns for most of the words in the experiment shows the synergistic ability of two approaches to account for both sources of non-conformity in a single phenomenon.

In the following chapter, I discuss implications of combining set-indexation and stochastic constraint ranking on learnability. Specifically, I will be addressing the acquisition of indexation, indexation at different levels of grammatical structure, differentiation between alternating and exceptional segments, and whether there could be one set of cues that allows the learner to acquire these different forms of non-conformity.

5 Learnability and Non-Conformity

In Chapter 4, I presented an OT analysis of Modern Hebrew spirantization, a phenomenon with respect to which there are two sources of non-conformity: exceptionality and variation. In this chapter, I address the problematic nature of the learnability of these two patterns of non-conformity, particularly when both occur in a single phenomenon, i.e. in Modern Hebrew spirantization.

I begin this chapter with a discussion of the mechanisms involved in the acquisition of set-indexation. I then provide an overview of lexical indexation and examine the implications of extending it not only to segments, but to other elements of the grammar in Section 5.2. I close the chapter with a discussion of the predictions of the combined model proposed in Chapter 4 and its implications for cues in acquisition of patterns of non-conformity.

5.1 Acquisition of Indexation

Although set indexation is not an element that all learners make use of, it is readily available for the learner as a part of the grammar. When a learner encounters a lexical unit that does not conform to the regular patterns of the grammar, indexation is employed once it is determined (statistically) that the non-conformity is not due to speech errors or variation (Pater 2000). In this section, I describe the acquisition of indexation as proposed by Pater (2000) which assumes Tesar and Smolensky's (1998) Error-Driven Constraint Demotion, rather than the Gradual Learning Algorithm.[26]

In error-driven learning, when a learner is exposed to a novel form, the new form is run through the grammar (in the form of an input) to determine whether the current constraint hierarchy derives the correct output. If the output matches the novel form, no action is necessary. If not, the constraint hierarchy must be adjusted. Winner ~ Loser pairs help determine whether constraints prefer optimal ('winner') or suboptimal ('loser') candidates for the input. When the optimal candidate for a novel form incurs a fatal violation, a re-ranking of the current active constraints is attempted (Pater 2005). Thus, Winner ~ Loser pairs are the driving force for constraint demotion, re-ranking and, in cases of exceptionality, set-indexation.

If re-ranking is insufficient to account for both the novel form and those already present in the grammar, the novel form is deemed exceptional. The algorithm does this by considering all learned data including the novel form and looking at frequency for each of the patterns. The more frequent pattern emerges as the regular, and the other is the exceptional pattern causing indexation. The dominated constraint, which the exceptional form obeys, is then cloned and indexed to a set in which the exceptional form is now a member, and the newly indexed constraint is ranked above the faithfulness constraint that the exceptional form violates.

This is illustrated with a hypothetical language (from Pater 2005) in (20). As seen in (a.) and (b.), codas are disallowed in this language, with /pak/ surfacing as [pa] and

[26] Unlike the Gradual Learning Algorithm which allows for demotion and promotion of constraints, Error-Driven Constraint Demotion only allows for the demotion of constraints.

/lot/ surfacing as [lo]. However, coda deletion has some exceptions, as evidenced in (c.) where /tak/ surfaces as [tak]. The learner is able to assume coda deletion in this language because of the presence of inflected forms in which the suffix -a is added to the base form and, in the case of (a.) and (b.) they contain the stem-final consonant not present in the simple form to which final coda deletion applied.

(20) Coda deletion and exceptionality

a. /pak/ → [pa] /pak+a/ → [paka]
b. /lot/ → [lo] /lot+a/ → [lota]
c. /tak/ → [tak] /tak+a/ → [taka]

In order to account for the regular forms in (20), NoCoda must dominate Max. In tableaux using Winner ~ Loser pairs, a W is entered when it is the winner that incurs fewer violations of the constraint in question and an L is entered when it is the loser. In the tableau in Table 87, we see that the Winner ~ Loser pairs for (a.) and (b.) are accounted for using this ranking (with the winner obeying the dominating constraint). However, the winner for the exceptional form in (c.) cannot be accounted for since it incurs a violation of NoCoda.

Table 87. Exceptionality in coda deletion

	Input	W ~ L	**NoCoda**	**Max**
a.	pak	pa ~ pak	W	L
b.	lot	lo ~ lot	W	L
c.	tak	tak ~ ta	L	W

Since the exceptional form [tak] obeys lower-ranked MAX, this constraint is cloned and indexed to an exceptional set (Set 1), of which [tak] is now a member. The indexed constraint can only be violated by members of the set to which it is indexed. The ranking of the newly indexed MAX_1 constraint above NOCODA correctly derives all forms in (20). This is illustrated in Table 88.

Table 88. Cloning of Max to account for exceptionality

	Input	W ~ L	**MAX_1**	**NOCODA**	**MAX**
a.	pak	pa ~ pak		W	L
b.	lok	lo ~ lok		W	L
c.	tak_1	tak ~ ta	W	L	W

According to Pater, once a word is deemed exceptional, it is assigned an indexed (faithfulness) constraint which is ranked as needed in the constraint hierarchy. Pater (2005) states that "learners are initially conservative, in that when they encounter a word that requires an adjustment to the grammar, they first assume that this adjustment is specific to that word." Suppose the hypothetical language in (20) also had the words [net], [bak], and [kap]. The learner would initially assign each of these to a separate exceptional set, each with its own indexed clone of MAX, as seen in (21).

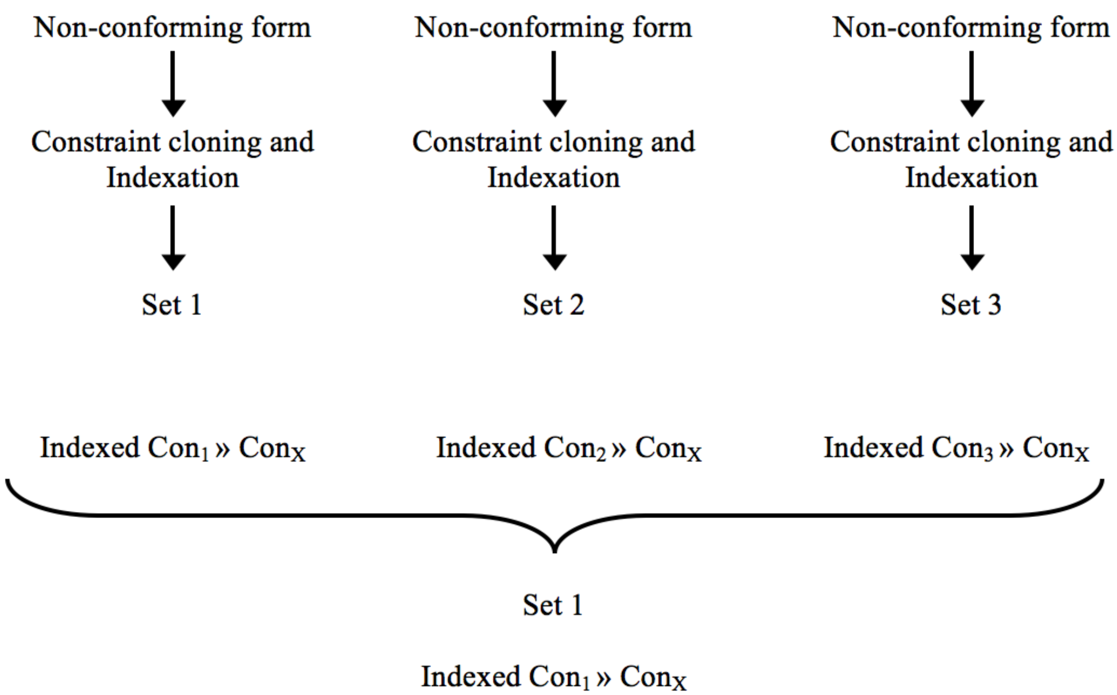
(21) Set indexation for additional exceptions

$[\text{net}]_2$ MAX_2
$[\text{bak}]_3$ MAX_3
$[\text{kap}]_4$ MAX_4

Constraint ranking:
MAX_1 , MAX_2 , MAX_3 , MAX_4 » NoCoda » MAX

If there are multiple clones of a particular constraint with the same ranking in the hierarchy, as is the case with MAX$_1$, MAX$_2$, MAX$_3$, and MAX$_4$, these (along with their corresponding sets) are collapsed into a single lexically specific constraint. In the case of the scenario in (21), this would result in the ranking MAX$_1$ » NoCoda » MAX and the assignment of all exceptional words to Set 1. This is schematized in Figure 26.

Figure 26. Schema for learning and collapsing indexation



Note that learning and indexation is frequency driven. This means that a learner will not create exception sets and set-indexed constraints until it becomes clear that the exception in question is not merely a performance error or variation. Additionally, according to Becker (2009), once the learner has accounted for the forms in her grammar, novel forms are either assigned set membership or are placed in the general set based on the relative frequency of exceptional and regular forms in the language.[27]

In a phenomenon such as Modern Hebrew spirantization, which contains both variation and exceptionality, the learner is forced to rely heavily on frequency to decide whether a form is to be assigned set membership as exceptional or is simply a variant of an alternating form. In Modern Hebrew, non-alternation with respect to spirantization is frequent in the lexicon, which may be the leading drive for the high level of acceptability of variation in alternating forms. It should be noted that, in many cases, alternation and participation in spirantization in Modern Hebrew is encoded in the orthography, with different graphemes being used to distinguish between alternating and non-alternating segments (e.g. /k/ → [k]/[χ] is written as כ whereas /k/ → [k] (*<q) is written as ק). The orthographic representation of exceptions undoubtedly contributes to speakers' learning these exceptions, but also explains why children only attain full mastery of the Modern Hebrew phonological system around the age of 12 (Ravid 1995).

5.2 Indexation at Different Levels of the Grammatical Hierarchy

Prior to discussing the issues associated with the acquisition of two sources of non-conformity in a single grammar, this section looks at the different levels of the grammatical hierarchy at which indexation for exceptionality can take place.

The idea that exceptions are marked in some way in the mental lexicon is not novel. In fact, this dates back to pre-generative accounts (e.g. Mathesius 1929), and there

[27] See Coetzee (2008) for an account where novel items are non-alternating by default, relying only on input-output correspondence rather than probabilistic patterning found in the grammar.

are many examples of lexical indexation of constraints and constraint rankings in the recent literature (Itô & Mester 1995, McCarthy & Prince 1995, Inkelas et al. 1997, Itô & Mester 1999, Pater 2000). In this section, I consider evidence for lexical indexation at various levels of the grammatical hierarchy. I begin with a brief overview of work by Pater (2000, 2005, 2006) with indexation at the word and morpheme levels. In Section 5.2.2, I describe Becker's (2009) Cloning Recursive Constraint Demotion algorithm and discuss how it handles words and morphemes. I then discuss the proposed extension of Pater's approach to the segmental level as it was presented in the previous chapter in Section 5.2.3.

5.2.1 Indexation at the word and morpheme level

As summarized in Section 2.7.2.1, Pater (2000) initially proposed set-indexation in OT to account for non-uniformity in English secondary stress. In Pater's analysis, indexed words (outputs) are forms whose secondary stress matches the primary stress of the stem from which the candidate is derived (e.g. *stem*: accrédit ~ *derivation*: accrèditátion). Pater proposes that words are indexed for set membership and that each set can have its own collection of set-specific constraints. General (i.e. non-set-specific) constraints can be ranked separately from their set-specific counterparts to allow members of different sets to behave differently. For indexed faithfulness constraints, the indexed *clone* constraint is ranked above the general constraint (and at least one other constraint) to allow exceptional patterns to surface.

Pater (2006) uses morpheme set membership and set-indexed faithfulness and markedness constraints to account for syncope in Yine (formerly known as Piro). In this language, some morphemes trigger deletion of a preceding vowel (e.g. the third person singular pronominal suffix /-lu/: /het*a*+lu/ → [hetlu] 'see it'), whereas syncope fails to apply before others (e.g. the anticipatory suffix /-nu/: /het*a*+nu/ → [hetanu] 'going to see'). Additionally, some morphemes that fail to trigger deletion undergo syncope themselves when placed before triggering suffixes (e.g. the verb theme suffix /-wa/ does not trigger syncope in the stem, but undergoes it before the nominalizing suffix /-lu/: /meyi+w*a*+lu/ → [meyiwlu] 'celebration', as does the anticipatory suffix /-nu/: /heta+nu+lu/ → [hetanru]). Finally, there are exceptional suffixes that neither trigger syncope nor undergo it (e.g. the suffix /-wa/ 'yet, still': /heta+w*a*+lu/ → [hetaw*a*lu] 'going to see him yet'). Since whether a morpheme triggers or undergoes syncope cannot be determined by any phonological property (as is evidenced by the homophones /-wa/, which behave differently), there must be another way to distinguish the two morphemes from one another.

To account for Yine syncope, Pater uses an alignment constraint, ALIGN-SUF-C ('the left edge of a suffix coincides with the right edge of a consonant'), to promote syncope, and MAX ('do not delete') penalizes syncope. This analysis employs indexation of both markedness and faithfulness constraints. Trigger morphemes are indexed to a set (L1) with a cloned iteration of ALIGN-SUF-C and blocking morphemes to a different set (L2) with a clone of MAX. The final constraint ranking is MAX-L2 » ALIGN-SUF(L1)-C » MAX » ALIGN-SUF-C. In Table 89, we see the ability of markedness and faithfulness indexation to capture Yine syncope. The first tableau has the suffix /-lu/ which triggers syncope in the preceding element (in this case, the suffix /-nu/). Candidate (a), [hetanulu], incurs a fatal violation of ALIGN-SUF(L1) because /-lu/ requires a consonant to precede it. [hetanru] is the winning candidate, violating only MAX, which is ranked below the other relevant constraints. The second tableau also contains the syncope-triggering suffix /-lu/. In this case, however, the preceding suffix is the /-wa/ that does not undergo syncope. To ensure that the presence of /-lu/ will not trigger syncope in this suffix, it is indexed to a set whose corresponding MAX constraint is ranked above ALIGN-SUF(L1). Candidate (b), [hetawlu], incurs a fatal violation of MAX-L2, preventing syncope and resulting in the selection of candidate (a), [hetawalu].

Table 89. Tableau for set-indexation of markedness and faithfulness constraints

Input	Output	**MAX-L2**	**ALIGN-SUF(L1)**	**MAX**
heta+nu+lu$_{L1}$	a. hetanulu		*!	
	☞b. hetanru			*
heta+wa$_{L2+}$lu$_{L1}$	☞a. hetawalu		*	
	b. hetawlu	*!		*

Whether to clone a markedness or faithfulness constraint is determined by the type of exceptionality the morpheme displays; cloned markedness constraints apply to triggering morphemes and cloned faithfulness constraints apply to blocking morphemes.

5.2.2 The Cloning Recursive Constraint Demotion algorithm

Becker (2009) proposes an algorithm capable of generating indexed constraints to account for exceptional words and morphemes. In the Cloning Recursive Constraint Demotion algorithm, an indexation (cloning) mechanism is added to the Recursive Constraint Demotion (RCD) algorithm (Tesar 1998, Tesar & Smolensky 1998, Prince 2002). In this algorithm, constraint cloning is used for inconsistency resolution with the purpose of aiding the learner in discovering distinct phonological realizations within morphological categories in their grammar.

According to Becker's algorithm, set-indexation first assumes exceptionality at the lexical level, indexing morphemes only after the learner has discovered a pattern among morphemes:

> To achieve speakers' ability to replicate lexical trends, lexical items are added to the domain of clones, based on each item's behavior with respect to the clone. Since the clones assess the morpho-phonological properties of lexical items, it follows...that the domains of clones contain lexical items that share morpho-phonological properties. (Becker, 170)

The Cloning RCD discovers morpho-phonological patterns by breaking down words into their stem and outermost affixation (or 'immediate morphological constituents'). The separated stem and affix are then added to the domain of the cloned constraint, allowing the learner to search for patterns among other stems and affixes indexed to the same cloned constraint and to learn the behavior of each stem and affix combination separately (if this was observed in the language). The Cloning RCD is inherently cyclical. The grammar constantly evolves with the presentation of new input, allowing indexation to be determined at different stages. In Section 5.2.3 I propose the further separation of words and morphemes to allow for exceptional segments, as evidenced in Modern Hebrew spirantization.

5.2.3 Extending indexation to the segmental level

In Chapter 4, I proposed an extension of Pater's (2000) set-indexation to the segmental level. In my analysis, I provide evidence of exceptionality at the segmental level from Modern Hebrew spirantization. The three consonant pairs involved in spirantization ([b]/[v], [p]/[f], and [k]/[χ]) alternate, with fricatives occurring in post-vocalic context and stops occurring elsewhere. Exceptions to spirantization are segments which occur as non-alternating segments in verbal paradigms leading to instantiations of post-vocalic stops and word-initial or post-consonantal fricatives. In Chapter 4, I argue that exceptionality in Modern Hebrew spirantization must be encoded at the segmental level given the existence of hybrid words, which contain both an alternating segment and a non-alternating segment. In what follows, I present the mechanisms for learning exceptionality at the segmental level.

According to the Cloning RCD algorithm, when the learner is initially exposed to a word containing an exceptional segment, that word is broken down to its stem and immediate affixations.[28] Once the learner encounters several words within a root's paradigm, she discovers that the root is exceptional. Once a root is deemed exceptional, it is indexed to a corresponding constraint. Indexation fails, however, when a hybrid root or word is encountered. Unable to index the entire word or root, the indexation mechanism

[28] Becker (2009) defines the stem as the base form to which affixations are added. In my analysis of Modern Hebrew, words are broken down into the tri-consonantal root and inflectional affixes.

has to find the level at which indexation and constraint cloning result in the correct output. For hybrids in Modern Hebrew spirantization, this is the segmental level, as schematized in Figure 27. Once the learner identifies the three forms in A as alternating forms, she is able to label the three forms in B as exceptional. Breaking down the words into their roots and inflections, the learner sees that the same inflection can result in both regular and exceptional roots, and assumes the roots in B (/χlm/, /dkr/, /fʃl/, and /bkr/) are the exceptional elements in these words. In Modern Hebrew spirantization, this indexation also correlates with the cloning of IDENT[cont] to this exceptional set and the ranking of the cloned constraint above the markedness constraints driving spirantization.

The learner is then presented with the word [levaker] in C. This word shares its root, /bkr/, with [biker], a previously encountered word indexed as exceptional. Running the word [levaker] through the current grammar as an exceptional root (along with its inflection), the learner can only produce [lebaker], which has two post-vocalic stops. With indexation at the root level, the learner can only produce a regular paradigm with the words [biker] and [lebaker], or an exceptional paradigm with the words [viχer] and [levaχer]. Having heard [biker] and [levaker], the learner seeks to allow for alternation and exceptionality within the root. By indexing non-alternating /k/ as exceptional, the learner is able to achieve this. Alternately, if the learner is exposed to the word [levaker] initially, the root /bkr/ would still be labeled exceptional, due to the presence of the post-vocalic [k]. The learner would then assume that both the root-initial [v] and root-medial [k] were non-alternating. Once she is presented with the related word [biker] with a word-initial stop, the learner would deduce that the indexation for non-alternation must apply only to the /k/ and not the root-initial labial.

Figure 27. Schema for indexation at the segmental level

A. [baχa] → {/bχh/ + inflection1} = alternating (word-initial [b], post-vocalic [χ])
[tafar] → {/tfr/ + inflection1} = alternating (post-vocalic [f])
[katav] → {/ktb/ + inflection1} = alternating (word-initial [k], post-vocalic [v])

B. [χalam] → {/χlm/ + inflection1} = exceptional (word-initial [χ])
[fiʃel] → {/fʃl/ + inflection1} = exceptional (word-initial [f])
[biker] → {/bkr/ + inflection1} = exceptional (post-vocalic [k])

Exceptional set = {/χlm/, /dkr/, /fʃl/, /bkr/}

C. [levaker] → {/bkr/ + inflection} = hybrid (post-vocalic [k] is exceptional,
(already knows [biker]) post-vocalic [v] is alternating)

D. /bkr/ = hybrid root
/b/ = alternating
/k/ = exceptional

Once the learner is exposed to different patterns of indexation, she can then choose to make generalizations (i.e. all exceptionality is at the segmental level), or she can choose to only index hybrids for segmental exceptionality. A benefit to not forcing the learner to index all exceptionality with respect to Modern Hebrew spirantization at the segmental level is the possibility of indexing certain positions in a morphological template as exceptional.

In Modern Hebrew, when [b], [p], and [k] are the second consonant in a root in the piʔel binyan, they are always non-alternating post-vocalic stops.[29] Examples of these

[29] See Appendix B for the conjugations of this and other binyanim.

are the roots /spr/ ‘to tell’ ([siper], [lesaper]) and /kbl/ ‘to receive’ ([kibel], [lekabel]). This results in whole paradigms with a non-alternating post-vocalic stop. If we do not limit the indexation for a particular phenomenon to a specific level of the grammar, the learner can opt to index this consonant position as exceptional once she has heard enough exceptional forms from the piʔel binyan to make this generalization. This allows the learner to index both segments and morphological templates to the same set of exceptions with respect to a particular pattern or phenomenon.

I consider non-alternating segments exceptional because of the possibility of their occurring in positions not predicted by the spirantization distribution (e.g. stops in post-vocalic position and fricatives in non-post-vocalic positions). Of course, since these segments do not alternate, they also occur in environments *predicted* by the spirantization distribution. Crucially, only certain instantiations of a given segment (i.e. some instances of /k/ but not others) are exceptional in this sense and, thus, candidates for set-indexation. Patterns that can be described in terms of natural classes, e.g. a language prohibiting codas but allowing syllable-final /k/, are not candidates for set-indexation, as they can be accounted for with general markedness constraints.

Indexation of markedness can also be extended to the segmental level, where it plays a similar role as at the morpheme level (see Section 5.2.1). Consider a hypothetical language which essentially lacks spirantization (i.e. IDENT-IO[cont] dominates *V-STOP), but has a few instances in which post-vocalic stops are realized as fricatives. The exceptional spirantization of these stops could be accounted for by indexing them to a constraint *V-STOP$_1$, which dominates IDENT-IO[cont]. The tableaux in Table 90 illustrate this.

Table 90. Indexation of markedness at the segmental level

Input	Output	***V-STOP$_1$**	**IDENT-IO[cont]**	***V-STOP**
/daba/	☞a. daba			*
	b. dava		*!	
/dab$_1$a/	a. daba	*!		*
	☞b. dava		*	

Thus, cloned markedness constraints indexed at the segmental level can characterize exceptional "undergoers" (e.g. of spirantization), with the constraint functioning as the trigger of the phenomenon, while cloned faithfulness constraints characterize exceptional "non-undergoers," with the constraint functioning as the blocker. This raises the possibility of accounting for the same set of exceptions by indexing the undergoers to markedness or the non-undergoers to faithfulness. Of course, Occam's razor suggests that whether the undergoers or the non-undergoers are deemed exceptional with respect to a given phenomenon should boil down to their relative frequency in the language, with those in the minority being indexed as exceptions so as to minimize the total number of indexed segments. Further research into this overlap in labor between indexation of markedness versus faithfulness constraints would be valuable.

Summing up, I propose that Becker's (2009) proposal could be extended to account for exceptionality at progressively more fine-grained levels of structure. Extending exceptional set-indexation (and indexation of faithfulness and markedness constraints) from the word to the morpheme and then to the segmental level suggests that this approach could be further applied not only to supra- and sub-segmental levels of structure, such as templatic root positions, but also to tone.

5.3 Learning Two Patterns of Non-Conformity in a Single Phenomenon

In Chapter 4, I proposed a model that uses constraint indexation and stochastic rankings to account for exceptionality and variation in Modern Hebrew spirantization. I also demonstrated that both components were necessary to account for two patterns of non-conformity in a single phenomenon. In this section, I discuss a possible connection between exceptionality and variation, the implications of the combined model, and its predictions for cues of non-conformity. I then pose questions for future research concerning the learnability of non-conformity.

5.3.1 A connection between exceptionality and variation

The experiment described in Chapter 3 showed variation to be acceptable in both alternating and exceptional forms. However, exceptional segments showed significantly lower rates of acceptability of variation than did alternating segments. Adam (2002) hypothesized that the high rate of variation in alternating segments stems from the fact that there are many exceptions to that alternation. She further predicts that the segments participating in Modern Hebrew spirantization are evolving toward non-alternation. This is in line with Pater's (2005) proposal of imposing a maximum size on the set of components targeted by an indexed constraint.[30] Once that number is reached, he argues, the indexation should be removed from the lexically indexed constraint, and all lower-ranked instantiations of that constraint should be deleted. In Modern Hebrew, exceptional segments are indexed to a set whose corresponding faithfulness constraints dominate the relevant markedness constraints. Under Pater's proposal, the newly assigned general faithfulness constraint would be ranked above the relevant markedness constraints, preventing any alternation from taking place.

While exceptions typically do not exhibit variation (Becker 2009), the results of the experiment in Chapter 3 show significant acceptability of variation in exceptional segments in Modern Hebrew spirantization. This suggests that exceptionality, besides driving the high level of variation in alternating segments, is also affected by it, resulting in variation in exceptionality. To accurately describe the status of this phenomenon and the direction of alternation, a longitudinal study of spoken Hebrew is needed.

The acceptability of variation in both alternation and exceptionality complicates the learning process, and makes it difficult to account for both types of non-conformity using only one mechanism. Recall that, as described in Section 4.3.1, the low noise levels and fixed constraint distributions of the GLA make it impossible for stochastic constraint rankings to account for the differences in variation between exceptions and alternating segments without the assistance of set-indexation. Similarly, while set-indexation is able to account for a grammar containing only alternating and exceptional segments, we are

[30] The actual maximum number imposed is not stated in Pater's proposal. Rather, this number is assumed to correlate to the number of lexical items in the grammar.

unable to account for the gradient nature of variation found in the experiment without stochastic constraint ranking.[31]

5.3.2 Cues for non-conformity and further questions

Since it is only possible to account for exceptionality and variation in Modern Hebrew spirantization using two mechanisms, we must ask how the learner distinguishes between variation in alternation and exceptionality (which also exhibits variation). Recall that, in order to combine stochastic constraint ranking and set-indexation in the analysis presented in Chapter 4, exceptional segments were already assumed to be indexed when they were entered as the input for the GLA to generate outputs for variation and exceptionality simultaneously. This makes indexation a rather static process that is already assumed once the learner is confronted with data about variation, which is not in line with Becker's (2009) Cloning RCD Algorithm. Since, in language acquisition, alternation, exceptionality and variation are not presented to the learner chronologically, this leaves open the question of how a learning algorithm could acquire set indexation and stochastic ranking simultaneously. In their current iterations, neither the GLA nor the Cloning RCD algorithm is able to account for this interaction of alternation, exceptionality, and variation.

This also leaves open the question of whether this mean that there are two distinct cues for these two patterns of non-conformity. Or is it that the learner is sensitive to small statistical differences between non-conforming segments which are more skewed to not

[31] The Cloning RCD algorithm enables set-indexation to account for *free* (non-gradient) variation through the indexation of a variable form to two sets with two different rankings of the cloned constraint. Then, at any given iteration, the algorithm randomly selects a set for the variable form, allowing for variation.

conform (i.e. exceptional segments with lower rates of acceptability of variation) and other segments which are less likely to not conform (i.e. alternating segments showing higher rate of variation)?[32]

5.4 Summary of the Dissertation

This dissertation provided a comprehensive summary of the state of Modern Hebrew spirantization as it relates to verbal paradigms. Results from the experimental rating task demonstrated that variation is acceptable to some extent in both alternating and exceptional segments. Importantly, variation in exceptional segments was rated as less acceptable than variation in alternating segments, affirming that speakers distinguish between alternating and exceptional segments.

In the analysis of Modern Hebrew spirantization, the presence of hybrid words containing both an alternating and an exceptional segment suggests that exceptionality is encoded at the segmental level. To account for exceptionality as a segmental-level phenomenon, a proposal for the extension to Pater's (2000, 2005, 2006) set-indexation approach from the word and morpheme level to the segment is proposed, and its potential expansion to other levels of the grammar is explored.

The set-based approach and Stochastic OT (Boersma 1998, Hayes & MacEachern 1998, Zuraw 2000, Boersma & Hayes 2001, Hayes & Londe 2006) are combined to account for both sources of non-conformity. It is shown that the two mechanisms are neccessary in order to account for exceptionality and variation in a single phenomenon.

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[32] Recall that although variants of exceptional and alternating segments were rated as acceptable, in most cases they were rated less acceptable than the expected form.

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Appendixes

Appendix A: Target words for follow up study

Key: (E) = expected, (V) = variant, wi = word-initial, pv = post-vocallic, pc = post-consonantal

			(E)wi	*(V)wi*	*(E)pv*	*(V)pv*	*(E)pc*	*(V)pc*	*Gloss*
Alternating									
/b/									
Root-initial	בטל	/btl/	bitel	vitel	mevatel	mebatel			cancel
	בנה	/bnh/	bana	vana	livnot	libnot			Build
	ברר	/brr/	birer	virer	mevarer	mebarer			clarify
	בדק	/bdk/	badak	vadak	livdok	libdok			Check
Root-medial	סבל	/sbl/			saval	sabal	lisbol	lisvol	Suffer
	גבה	/gbh/			gava	gaba	ligbot	ligvot	Collect
	שבר	/ʃbr/			ʃavar	ʃabar	liʃbor	liʃvor	Break
	לבש	/lbʃ/			lavaʃ	labaʃ	lilboʃ	lilvoʃ	Wear
/p/									
Root-initial	פטר	/ptr/	piter	fiter	mefater	mepater			Fire
	פתח	/ptχ/	pataχ	fataχ	liftoaχ	liptoaχ			Open
	פגש	/pgʃ/	pagaʃ	fagaʃ	lifgoʃ	lipgoʃ			Meet
	פרק	/prk/	pirek	firek	mefarek	meparek			Take apart
Root-medial	תפס	/tps/			tafas	tapas	litpos	litfos	Catch
	שפך	/ʃpχ/			ʃafaχ	ʃapaχ	liʃpoχ	liʃfoχ	Pour
	נפש	/npʃ/			nafaʃ	napaʃ	linpoʃ	linfoʃ	Vacation
	ספר	/spr/			safar	sapar	lispor	lisfor	Count
/k/									
Root-initial	כתב	/ktv/	katav	χatav	liχtov	liktov			Write
	כבס	/kbs/	kibes	χibes	meχabes	mekabes			Launder
	כסה	/ksh/	kisa	χisa	meχase	mekase			Cover
	כעס	/kʔs/	kaas	χaas	liχos	likos			Be angered
Root-medial	זכה	/zki/			zaxa	zaka	lizkot	lizxot	Win
	שכב	/ʃkv/			ʃaxav	ʃakav	liʃkav	liʃxav	Lay down
	מכר	/mkr/			maχar	makar	limkor	limχor	Sell
	רכב	/rkb/			raχav	rakav	lirkav	lirχav	Ride

Key: (E) = expected, (V) = variant, wi = word-initial, pv = post-vocallic, pc = post-consonantal

			(E)wi	*(V)wi*	*(E)pv*	*(V)pv*	*(E)pc*	*(V)pc*	*Gloss*
Exceptional									
/k/ <*q									
Root-initial	קים	/kjm/	kijem	χijem	mekajem	meχajem			Fulfill
	קרא	/krʔ/	kara	χara	likro	liχro			Read
Root-medial	דקר	/dkr/			dakar	daχar	lidkor	lidχor	Poke, stab
	שקל	/ʃkʔ/			ʃaka	ʃaχa	liʃkoa	liʃχoa	Sink
/v/ <*w									
Root-initial	וידא	/vdʔ/	vida	bida	mevade	mebade			Validate,
	וטר	/vtr/	viter	biter	mevater	mebater			Concede
Root-medial	לוה	/lvi/			lava	laba	lilvot	lilbot	Escort
	טוה	/tvh/			tava	taba	litvot	litbot	Weave
/X/ <*h									
Root-initial	חזר/ חי	/χzr/ /χjh/	χazar	kazar	liχjot	likjot			Return/ Live
	חיך	/χjk/	χijeχ	kijeχ	meχajeχ	mekajeχ			Smile
Root-medial	בחן	/bχn/			baχan	bakan	livχon	livkon	Examine
	דחה	/dχh/			daχah	dakah	lidχot	lidkot	Postpone
/f/ source: borrowing									
Root-initial	פשל	/fʃl/	fiʃel	piʃel	mefaʃel	mepaʃel			Err
	פידח	/fdχ/	fideax	pideax	mefadeax	mepadeax			Joke
Root-medial	טלפן	/tlfn/					tilfen	tilpen	Call
							metalfen	metalpen	

2 regularly-alternating per root										
כפה	/kph/	kafa	χafa	kappa	χapa	liχpot	likpot	liχfot	likfot	Force
בכה	/bkh/	baχa	vaχa	baka	vaka	livkot	libkot	livχot	libχot	Cry
Hybrids										
בקש	/bkʃ/	bikeʃ	vikeʃ	biχeʃ	viχeʃ	levakeʃ	lebakeʃ	levaχeʃ	lebaχeʃ	Request
בקר	/bkr/	biker	viker	biχer	viχer	levaker	lebaker	levaχer	lebaχer	Visit
בחר	/bχr/	baχar	vaχar	bakar	vakar	livχor	libχor	livkor	libkor	Choose
קפא	/kpʔ/	kafa	χafa	kappa	χapa	likpo	liχpo	likfo	liχfo	Joke

Appendix B: Binyanim in Modern Hebrew

I. PA’AL [kanas] - ‘to gather’

Past	Plural	Singular	Temp-Pl	Temp-Sg
1st	[kaˈnasnu]	[kaˈnasti]	CaCaCnu	CaCaCti
2nd masc	[kaˈnastem]	[kaˈnasta]	CaCaCtem	CaCaCta
2nd fem	[kaˈnasten]	[kaˈnast]	CaCaCten	CaCaCt
3rd masc	[kanˈsu]	[kaˈnas]	CaCCu	CaCaC
3rd fem		[kanˈsa]		CaCCa

Present	Plural	Singular	Temp-Pl	Temp-Sg
masculine	[konˈsim]	[koˈnes]	CoCCim	CoCeC
feminine	[konˈsot]	[koˈneset]	CoCCot	CoCeCet

Future	Plural	Singular	Temp-Pl	Temp-Sg
1st	[niχˈnos]	[eχˈnos]	niCCos	eCCoC
2nd masc	[tiχenˈsu]	[tiχˈnos]	tiCeCCu	tiCCoC
2nd fem		[tiχenˈsi]		tiCeCCi
3rd masc	[iχenˈsu]	[iχˈnos]	iCeCCu	iCCoC
3rd fem		[tiχˈnos]		tiCCoC

II. HIF’IL [hiχnis] - ‘to insert’

Past	Plural	Singular	Temp-Pl	Temp-Sg
1st	[hiχˈnasnu]	[hiχˈnasti]	hiCCaCnu	hiCCaCti
2nd masc	[hiχˈnastem]	[hiχˈnasta]	hiCCaCtem	hiCCaCta
2nd fem	[hiχˈnasten]	[hiχˈnast]	hiCCaCten	hiCCaCt
3rd masc	[hiχˈnisu]	[hiχˈnis]	hiCCiCu	hiCCiC
3rd fem		[hiχˈnisa]		hiCCiCa

Present	Plural	Singular	Temp-Pl	Temp-Sg
masculine	[maχniˈsim]	[maχˈnis]	maCCiCim	maCCiC
feminine	[maχniˈsot]	[maχniˈsa]	maCCiCot	maCCiCa

Future	Plural	Singular	Temp-Pl	Temp-Sg
1st	[naχˈnis]	[aχˈnis]	naCCos	aCCiC
2nd masc	[taχˈnisu]	[taχˈnis]	taCCiCu	taCCiC
2nd fem		[taχˈnisi]		taCCiCi
3rd masc	[jaχˈnisu]	[jaχˈnis]	jaCCiCu	jaCCiC
3rd fem		[taχˈnis]		taCCiC

III. PI’EL [kines] - ‘to convene’

Past	Plural	Singular	Temp-Pl	Temp-Sg
1st	[ki'nasnu]	[ki'nasti]	CiCaCnu	CiCaCti
2nd masc	[ki'nastem]	[ki'nasta]	CiCaCtem	CiCaCta
2nd fem	[ki'nasten]	[ki'nast]	CiCaCten	CiCaCt
3rd masc	[kin'su]	[ki'nes]	CiCCu	CiCeC
3rd fem		[kin'sa]		CiCCa

Present	Plural	Singular	Temp-Pl	Temp-Sg
masculine	[meχan'sim]	[meχa'nes]	meCaCCim	meCaCeC
feminine	[meχan'sot]	[meχa'neset]	meCaCCot	meCaCeCet

Future	Plural	Singular	Temp-Pl	Temp-Sg
1st	[neχa'nes]	[aχa'nes]	neCaCes	aCaCeC
2nd masc	[teχan'su]	[teχa'nes]	teCaCCu	teCaCeC
2nd fem		[teχan'si]		teCaCCi
3rd masc	[jeχan'su]	[jeχa'nes]	jeCaCCu	jeCaCeC
3rd fem		[teχa'nes]		teCaCeC

IV. HITPA’EL [hitkanes] - ‘to assemble’

Past	Plural	Singular	Temp-Pl	Temp-Sg
1st	[hitka'nasnu]	[hitka'nasti]	hitCaCaCnu	hitCaCaCti
2nd masc	[hitka'nastem]	[hitka'nasta]	hitCaCaCtem	hitCaCaCta
2nd fem	[hitka'nasten]	[hitka'nast]	hitCaCaCten	hitCaCaCt
3rd masc	[hitkan'su]	[hitka'nes]	hitCaCCu	hitCaCeC
3rd fem		[hitkan'sa]		hitCaCCa

Present	Plural	Singular	Temp-Pl	Temp-Sg
masculine	[mitkan'sim]	[mitka'nes]	mitCaCCim	mitCaCeC
feminine	[mitkan'sot]	[mitka'neset]	mitCaCCot	mitCaCeCet

Future	Plural	Singular	Temp-Pl	Temp-Sg
1st	[nitka'nes]	[etka'nes]	nitCaCes	etCaCeC
2nd masc	[titkan'su]	[titka'nes]	titCaCCu	titCaCeC
2nd fem		[titkan'si]		titCaCCi
3rd masc	[itkan'su]	[itka'nes]	itCaCCu	itCaCeC
3rd fem		[titka'nes]		titCaCeC

V. <u>NIF’AL</u> (passive of PA’AL) **[niχnas] - ‘to enter’**

Past	Plural	Singular	Temp-Pl	Temp-Sg
1st	[niχ'nasnu]	[niχ'nasti]	niCCaCnu	niCCaCti
2nd masc	[niχ'nastem]	[niχ'nasta]	niCCaCtem	niCCaCta
2nd fem	[niχ'nasten]	[niχ'nast]	niCCaCten	niCCaCt
3rd masc	[niχne'su]	[niχ'nas]	niCCeCu	niCCaC
3rd fem		[niχne'sa]		niCCeCa

Present	Plural	Singular	Temp-Pl	Temp-Sg
masculine	[niχna'sim]	[niχ'nas]	niCCaCim	niCCaC
feminine	[niχna'sot]	[niχ'neset]	niCCaCot	niCCeCet

Future	Plural	Singular	Temp-Pl	Temp-Sg
1st	[nika'nes]	[eka'nes]	niCaCeC	eCaCeC
2nd masc	[tikan'su]	[tika'nes]	tiCaCCu	tiCaCeC
2nd fem		[tikan'si]		tiCaCCi
3rd masc	[ikan'su]	[ika'nes]	iCaCCu	iCaCeC
3rd fem		[tika' nes]		tiCaCeC

VI. <u>HUF’AL</u> (passive of HIF’IL) **[huχnas] - ‘to be inserted’**

Past	Plural	Singular	Temp-Pl	Temp-Sg
1st	[huχ'nasnu]	[huχ'nasti]	huCCaCnu	huCCaCti
2nd masc	[huχ'nastem]	[huχ'nasta]	huCCaCtem	huCCaCta
2nd fem	[huχ'nasten]	[huχ'nast]	huCCaCten	huCCaCt
3rd masc	[huχne'su]	[huχ'nas]	huCCeCu	huCCaC
3rd fem		[huχne'sa]		huCCeCa

Present	Plural	Singular	Temp-Pl	Temp-Sg
masculine	[muχna'sim]	[muχ'nas]	muCCaCim	muCCaC
feminine	[muχna'sot]	[muχ'neset]	muCCaCot	muCCeCet

Future	Plural	Singular	Temp-Pl	Temp-Sg
1st	[nuχ'nas]	[uχ'nas]	nuCCaC	uCCaC
2nd masc	[tuχen'su]	[tuχ'nas]	tuCeCCu	tuCCaC
2nd fem		[tuχne'si]		tuCCeCi
3rd masc	[juχen'su]	[juχ'nas]	juCeCCu	juCCaC
3rd fem		[tuχ'nas]		tuCCaC

VII. <u>PU’AL</u> (passive of PI’EL) **[kunas] - ‘to be convened’**

Past	Plural	Singular	Temp-Pl	Temp-Sg
1st	[ku'nasnu]	[ku'nasti]	CuCaCnu	CuCaCti
2nd masc	[ku'nastem]	[ku'nasta]	CuCaCtem	CuCaCta
2nd fem	[ku'nasten]	[ku'nast]	CuCaCten	CuCaCst
3rd masc	[kun'su]	[ku'nas]	CuCCu	CuCaC
3rd fem		[kun'sa]		CuCCa

Present	Plural	Singular	Temp-Pl	Temp-Sg
masculine	[meχuna'sim]	[meχu'nas]	meCuCaCim	meCuCaC
feminine	[meχuna'sot]	[meχu'neset]	meCuCaCot	meCuCeCet

Future	Plural	Singular	Temp-Pl	Temp-Sg
1st	[neχu'nas]	[aχu'nas]	neCuCaC	aCuCaC
2nd masc	[teχun'su]	[teχu'nas]	teCuCCu	teCuCaC
2nd fem		[teχun'si]		teCuCi
3rd masc	[jeχun'su]	[jeχu'nas]	jeCuCCu	jeCuCaC
3rd fem		[teχu'nas]		teCuCaC

Appendix C: Results of Combined Model in OT Soft

Result of Applying Gradual Learning Algorithm

OTSoft 2.3, release date 5/15/080

1. Ranking Values Found

103.792	Ident-IO[cont]1
102.125	*V-stop
101.139	*[+cont, -sib]
100.480	*StopStop
98.861	*Stop
-1,797.540	Ident-IO[cont]

2. Matchup to Input Frequencies

/bdk/	Input Fr.	Gen Fr.
badak	0.900	0.788
vadak	0.100	0.212

/bdk/	Input Fr.	Gen Fr.
livdok	0.642	0.722
libdok	0.358	0.279

/bkh/	Input Fr.	Gen Fr.
baXa	0.833	0.450
baka	0.071	0.338
vaka	0.048	0.000
vaXa	0.048	0.212

/bkh/	Input Fr.	Gen Fr.
livkot	0.614	0.509
libkot	0.333	0.279
libXot	0.035	0.000
livXot	0.018	0.212

/bkr/	Input Fr.	Gen Fr.
biker	0.783	0.617
biXer	0.022	0.171
viker	0.196	0.144
viXer	0.000	0.068

/bkr/	Input Fr.	Gen Fr.
mevaker	0.723	0.423
mebaker	0.255	0.338
mebaXer	0.021	0.000
mevaXer	0.000	0.239

/bkS/	Input Fr.	Gen Fr.
bikeS	0.685	0.617
biXeS	0.037	0.171
vikeS	0.241	0.144
viXeS	0.037	0.068

/bkS/	Input Fr.	Gen Fr.
mevakeS	0.574	0.423
mebakeS	0.393	0.338
mebaXeS	0.033	0.000
mevaXeS	0.000	0.239

/bnh/	Input Fr.	Gen Fr.
bana	0.783	0.788
vana	0.217	0.212

/bnh/	Input Fr.	Gen Fr.
livnot	0.649	0.662
libnot	0.351	0.338

/brr/	Input Fr.	Gen Fr.
birer	0.854	0.788
virer	0.146	0.212

/brr/	Input Fr.	Gen Fr.
mevarer	0.818	0.662
mebarer	0.182	0.338

/btl/	Input Fr.	Gen Fr.
bitel	0.771	0.788
vitel	0.229	0.212

/btl/	Input Fr.	Gen Fr.
mevatel	0.720	0.662
mebatel	0.280	0.338

/bxn/	Input Fr.	Gen Fr.
baXan	0.949	0.881
bakan	0.051	0.119

/bxn/	Input Fr.	Gen Fr.
livXon	0.947	0.835
livkon	0.053	0.165

/bxr/	Input Fr.	Gen Fr.
baXar	0.685	0.669
bakar	0.056	0.119
vakar	0.019	0.000
vaXar	0.241	0.212

/bxr/	Input Fr.	Gen Fr..
livXor	0.673	0.615
libkor	0.073	0.110
libXor	0.236	0.225
livkor	0.018	0.051

/dkr/	Input Fr.	Gen Fr.
dakar	0.946	0.761
daXar	0.054	0.239

/dkr/	Input Fr.	Gen Fr.
lidkor	0.919	0.898
lidXor	0.081	0.102

/dxh/	Input Fr.	Gen Fr.
daXah	0.972	0.881
dakah	0.028	0.119

/dxh/	Input Fr.	Gen Fr.
lidXot	0.875	0.854
lidkot	0.125	0.146

/fdx/	Input Fr.	Gen Fr.
fideax	0.784	0.835
pideax	0.216	0.165

/fdx/	Input Fr.	Gen Fr.
mefadeax	0.833	0.881
mepadeax	0.167	0.

/fSl/	Input Fr.	Gen Fr.
fiSel	0.837	0.835
piSel	0.163	0.165

/fSl/	Input Fr.	Gen Fr
mefaSel	0.762	0.881
mepaSel	0.238	0.

/gbh/	Input Fr.	Gen Fr.
gava	0.925	0.662
gaba	0.075	0.338

/gbh/	Input Fr.	Gen Fr.
ligvot	0.507	0.466
ligbot	0.493	0.534

/k?s/	Input Fr.	Gen Fr.
kaas	1.000	0.788
Xaas	0.000	0.212

/k?s/	Input Fr.	Gen Fr.
liXos	0.708	0.662
likos	0.292	0.338

/kbs/	Input Fr.	Gen Fr.
kibes	0.614	0.788
Xibes	0.386	0.212

/kbs/	Input Fr.	Gen Fr.
meXabes	0.673	0.662
mekabes	0.327	0.338

/kjm/	Input Fr.	Gen Fr.
kijem	0.860	0.976
Xijem	0.140	0.024

/kjm/	Input Fr.	Gen Fr.
mekajem	1.000	0.761
meXajem	0.000	0.239

/kph/	Input Fr.	Gen Fr.
kafa	0.649	0.450
kapa	0.123	0.338
Xafa	0.053	0.212
Xapa	0.175	0.000

/kph/	Input Fr.	Gen Fr.
liXpot	0.507	0.509
likfot	0.194	0.000
likpot	0.104	0.279
liXfot	0.194	0.212

/kph1/	Input Fr.	Gen Fr.
kafa1	0.897	0.637
kapa1	0.103	0.338
Xafa1	0.000	0.024
Xapa1	0.000	0.000

/kph1/	Input Fr.	Gen Fr.
likfo	0.452	0.328
likpo	0.435	0.428
liXfo	0.048	0.068
liXpo	0.065	0.176

/kr?/	Input Fr.	Gen Fr.
kara	0.973	0.976
Xara	0.027	0.024

/kr?/	Input Fr.	Gen Fr.
likro	0.972	0.761
liXro	0.028	0.239

/ksh/	Input Fr.	Gen Fr.
kisa	0.773	0.788
Xisa	0.227	0.212

/ksh/	Input Fr.	Gen Fr.
meXase	0.623	0.662
mekase	0.377	0.338

/ktv/	Input Fr.	Gen Fr.
katav	0.972	0.788
Xatav	0.028	0.212

/ktv/	Input Fr.	Gen Fr.
liXtov	0.667	0.722
liktov	0.333	0.279

/lbS/	Input Fr.	Gen Fr.
lavas	0.783	0.662
labaS	0.217	0.338

/lbS/	Input Fr.	Gen Fr
lilboS	0.630	0.788
lilvoS	0.370	0.212

/lvh/	Input Fr.	Gen Fr.
lava	0.783	0.881
laba	0.217	0.119

/lvh/	Input Fr.	Gen Fr.
lilvot	0.868	0.835
lilbot	0.132	0.165

/mkr/	Input Fr.	Gen Fr.
limkor	0.712	0.788
limXor	0.288	0.212

/mkr/	Input Fr.	Gen Fr.
maXar	0.973	0.662
makar	0.027	0.338

/npS/	Input Fr.	Gen Fr.
linfoS	0.585	0.212
linpoS	0.415	0.788

/npS/	Input Fr.	Gen Fr.
nafaS	0.814	0.662
napaS	0.186	0.338

/pgS/	Input Fr.	Gen Fr.
pagaS	0.947	0.788
fagaS	0.053	0.212

/pgS/	Input Fr.	Gen Fr.
lifgoS	0.571	0.722
lipgoS	0.429	0.279

/prk/	Input Fr.	Gen Fr.
pirek	0.875	0.788
firek	0.125	0.212

/prk/	Input Fr.	Gen Fr.
mefarek	0.857	0.662
meparek	0.143	0.338

/ptr/	Input Fr.	Gen Fr.
piter	0.902	0.788
fiter	0.098	0.212

/ptr/	Input Fr.	Gen Fr.
mefater	0.923	0.662
mepater	0.077	0.338

/ptx/	Input Fr.	Gen Fr.
pataX	0.875	0.788
fataX	0.125	0.212

/ptx/	Input Fr.	Gen Fr.
liftoaX	0.783	0.722
liptoaX	0.217	0.279

/rkv/	Input Fr.	Gen Fr.
lirkav	0.694	0.788
lirXav	0.306	0.212

/rkv/	Input Fr.	Gen Fr.
raXav	0.837	0.662
rakav	0.163	0.338

/sbl/	Input Fr.	Gen Fr.
lisbol	0.706	0.788
lisvol	0.294	0.212

/sbl/	Input Fr.	Gen Fr.
saval	0.632	0.662
sabal	0.368	0.338

/Sbr/	Input Fr.	Gen Fr.
liSbor	0.632	0.788
liSvor	0.368	0.212

/Sbr/	Input Fr.	Gen Fr.
Savar	0.655	0.662
Sabar	0.345	0.338

/Sk?/	Input Fr.	Gen Fr.
liSkoa	0.755	0.976
liSXoa	0.245	0.024

/Sk?/	Input Fr.	Gen Fr.
Saka	0.947	0.761
SaXa	0.053	0.239

/Skv/	Input Fr.	Gen Fr.
liSkav	0.900	0.788
liSxav	0.100	0.212

/Skv/	Input Fr.	Gen Fr.
Saxav	0.949	0.662
Sakav	0.051	0.338

/spr/	Input Fr.	Gen Fr.
lispor	0.681	0.788
lisfor	0.319	0.212

/spr/	Input Fr.	Gen Fr.
safar	0.854	0.662
sapar	0.146	0.338

/Spx/	Input Fr.	Gen Fr.
liSpoX	0.740	0.788
liSfoX	0.260	0.212

/Spx/	Input Fr.	Gen Fr.
SafaX	0.778	0.662
SapaX	0.222	0.338

/tps/	Input Fr.	Gen Fr.
litfos	0.524	0.466
litpos	0.476	0.534

/tps/	Input Fr.	Gen Fr.
tafas	0.881	0.662
tapas	0.119	0.338

/tvh/	Input Fr.	Gen Fr.
litvot	0.750	0.854
litbot	0.250	0.146

/tvh/	Input Fr.	Gen Fr.
tava	0.744	0.881
taba	0.256	0.119

/vdh/	Input Fr.	Gen Fr.
vida	0.861	0.835
bida	0.139	0.165

/vdh/	Input Fr.	Gen Fr. In
mevade	0.729	0.881
mebade	0.271	0.119

/vtr/	Input Fr.	Gen Fr.
viter	0.947	0.835
biter	0.053	0.165

/vtr/	Input Fr.	Gen Fr.
mevater	0.778	0.881
mebater	0.222	0.119

/xjh/	Input Fr.	Gen Fr.
liXjot	0.972	0.881
likjot	0.028	0.119

/xjx/	Input Fr.	Gen Fr.
XijeX	0.971	0.835
kijeX	0.029	0.165

/xjx/	Input Fr.	Gen Fr.
meXajeX	0.921	0.881
mekajeX	0.079	0.119

/xzr/	Input Fr.	Gen Fr.
Xazar	0.947	0.835
kazar	0.053	0.165

/zkh/	Input Fr.	Gen Fr.
lizkot	0.833	0.788
lizxot	0.167	0.212

/zkh/	Input Fr.	Gen Fr.
zaxa	0.972	0.662
zaka	0.028	0.338

/tlfn/	Input Fr.	Gen Fr.
metalfen	0.513	0.835
metalpen	0.487	0.165

/tlfn/	Input Fr.	Gen Fr.
tilfen	0.535	0.835
tilpen	0.465	0.165

4. Ranking Value to Ranking Probability Conversion

The computed ranking values correspond to the following pairwise ranking probabilities:

.723 Ident-IO[cont]1 >> *V-stop
.827 Ident-IO[cont]1 >> *[+cont, -sib]
.88 Ident-IO[cont]1 >> *StopStop
.96 Ident-IO[cont]1 >> *Stop
>.999 Ident-IO[cont]1 >> Ident-IO[cont]

.637 *V-stop >> *[+cont, -sib]
.72 *V-stop >> *StopStop
.876 *V-stop >> *Stop
>.999 *V-stop >> Ident-IO[cont]

.592 *[+cont, -sib] >> *StopStop
.79 *[+cont, -sib] >> *Stop
>.999 *[+cont, -sib] >> Ident-IO[cont]

.717 *StopStop >> *Stop
>.999 *StopStop >> Ident-IO[cont]

>.999 *Stop >> Ident-IO[cont]

5. Active Constraints

A constraint is active if it causes the winning candidate to defeat a rival in at least one competition.

Active	Ident-IO[cont]1
Active	*V-stop
Active	*[+cont, -sib]
Active	*StopStop
Active	*Stop
Inactive	Ident-IO[cont]

6. Testing the Grammar: Details

The grammar was tested for 10000 cycles.
Average error per candidate: 2.170%
Learning time: 0.043 minutes

7. Parameter Values Used by the GLA

Initial Rankings   All constraints started out at the default value of 100.

Schedule for GLA Parameters

	Stage	Trials	PlastMark	PlastFaith	NoiseMark	NoiseFaith
1	125512	255122.000	2.0002.000	2.0002.000	2.0002.000	2.000
2	225512	255120.093	0.0930.093	0.0932.000	2.0002.000	2.000
3	325512	255120.004	0.0040.004	0.0042.000	2.0002.000	2.000
4	425512	255120.000	0.0000.000	0.0002.000	2.0002.000	2.000

There were a total of 102048 learning trials.
Data were presented non-stochastically, in exact proportions to their frequencies in the input file.

Appendix D: Stimuli for Pilot Study (Chapter 2)

Expected	Variation	Gloss
pizer	**f**izer	'spread' (m.)
pizra	**f**izra	'spread' (f.)
je**f**azer	je**p**azer	'will spread' (m.)
te**f**azer	te**p**azer	'will spread' (f.)
bikeʃ	**v**ikeʃ	'asked for' (m.)
bikʃa	**v**ikʃa	'asked for' (f.)
je**v**akeʃ	je**b**akeʃ	'will ask for' (m.)
te**v**akeʃ	te**b**akeʃ	'will ask for' (f.)
pagaʃ	**f**agaʃ	'met' (m.)
pagʃa	**f**agʃa	'met' (f.)
ji**f**goʃ	ji**p**goʃ	'will meet' (m.)
ti**f**goʃ	ti**p**goʃ	'will meet' (f.)
da**f**ak	da**p**ak	'knocked' (m.)
da**f**ka	da**p**ka	'knocked' (f.)
jid**p**ok (rarely)	jid**f**ok	'will knock' (m.)
tid**p**ok	jid**f**ok	'will knock' (f.)
ka**v**ar	ka**b**ar	'buried' (m.)
ka**v**ra	ka**b**ra	'buried' (f.)
jik**b**or	jik**v**or	'will bury' (m.)
tik**b**or	tik**v**or	'will bury' (f.)
kibes	**χ**ibes	'laundered' (m.)
kibsa	**χ**ibsa	'laundered' (f.)
je**χ**abes	je**k**abes	'will launder' (m.)
te**χ**abes	te**k**abes	'will launder' (f.)
kisa	**χ**isa	'covered' (m.)
kista	**χ**ista	'covered' (f.)
je**χ**ase	je**k**ase	'will cover' (m.)
te**χ**ase	te**k**ase	'will cover' (f.)
χa**f**ar	χa**p**ar	'dug' (m.)
χa**f**ra	χa**p**ra	'dug' (f.)
jiχ**p**or	jiχ**f**or	'will dig' (m.)
tiχ**p**or	tiχ**f**or	'will dig' (f.)
ʃa**v**ar	ʃa**b**ar	'broke' (m.)
ʃa**v**ra	ʃa**b**ra	'broke' (f.)
jiʃ**b**or	jiʃ**v**or	'will break' (m.)
tiʃ**b**or	tiʃ**v**or	'will break' (f.)
ma**χ**ar	ma**k**ar	'sold' (m.)
ma**χ**ra	ma**k**ra	'sold' (f.)
jim**k**or	jim**χ**or	'will sell' (m.)
tim**k**or	tim**χ**or	'will sell' (f.)

za**χ**ar	za**k**ar	‘remembered’ (m.)
za**χ**ra	za**k**ra	‘remembered’ (f.)
jiz**k**or	jiz**χ**or	‘will remember’ (m.)
tiz**k**or	tiz**χ**or	‘will remember’ (f.)